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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 62-111

HELICOPTER ROTOR BLADE EROSION PROTECTIVE MATERIALS

Task 1D121401A14169
(Formerly Task 9R38-01-017-69)

Contract DA 44-177-TC-836

December 1962

prepared by:

VERTOL DIVISION
The Boeing Company
Morton, Pennsylvania

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HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

In this report the Vertol Division, The Boeing Company, has conducted a literature search and laboratory test to select a suitable material to protect helicopter rotor blades from erosion. The Transportation Research Command concurs in the conclusions and "Present" recommendations contained in the report.

A follow-on program (flight test using polyurethane film as a protective strip on the leading edges of helicopter rotor blades) will be conducted in the near future and the final results published.

FOR THE COMMANDER:

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Project Engineer

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PHASE I
REPORT NO. R-296

PREPARED BY
VERTOL DIVISION
THE BOEING COMPANY
MORTON, PENNSYLVANIA

for
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

PREFACE

This report was prepared by Vertol Division, The Boeing Company, Engineering Materials and Processes Department under the U. S. Army Transportation Research Command Contract Number DA 44-177-TC-836. The contract was administered by Mr. E. Rouzee Givens, Project Engineer of USATRECOM Systems and Equipment Division, Fort Eustis, Virginia, and Major E. S. Wilkinson, Contract Administrator, USATRECOM Contracting Office, Fort Eustis, Virginia.

This document contains the test results, conclusions and recommendations of Phase I, Helicopter Rotor Blade Erosion Protective Material Development Program conducted during the period July 1, 1962, to October 15, 1962.

Acknowledgement is herewith made to Mr. E. Rouzee Givens, USATRECOM Project Engineer, and Mr. Jake Fortner and Captain Doug Haller, U. S. Army Aviation Board, for their technical advice and assistance.

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SUMMARY

The object of this program was to obtain an erosion resistant system capable of protecting helicopter rotor blades for 800 hours of desert operation. To determine their relative sand erosion resistance, 184 systems were tested.

Initial testing of all materials was accomplished in a modified blast cabinet with number 70 washed and dried silica sand. The flat specimens were located 6 inches from the nozzle and blasted at a 90 degree impingement angle. The elapsed time to erode through the specimen was recorded in minutes.

Materials with the better erosion resistances were fabricated and bonded to airfoil leading edge sections 10 inches long for sand erosion resistance testing on a 2½ foot radius whirling arm. Time limitations of the program did not permit development of an airfoil configuration of some materials, such as silicon carbide and nitrile and ethylene propylene rubbers, which had excellent flat panel impingement test results.

A standard whirling-arm test run consisted of 25 pounds of sand dropped from 8 bins in 13 minutes onto the specimens rotating at a tip speed of 600 feet per second. Control Specimens of .010 and .009 inch thick, full hard, 301 stainless steel sheet were used to measure the consistency of the impingement and whirling-arm tests, respectively.

On each of the four categories, the following specimens exhibited the most resistance to sand erosion:

Materials	Number of Runs To Failure
Polyurethane film BV 123*	8
Polyurethane film BV 124	6
Neoprene Liquid BV 197	5
Neoprene Liquid BV 204	4
Electroformed Nickel BV 43	2
Molybdenum Arc-Cast BV 27	1½
Polyvinyl Chloride Pressure Sensitive Tape BV 221	½
Polyvinyl Chloride Pressure Sensitive Tape BV 222	¼
(Full Hard 301 Stainless Steel Control BV 2)	(½)

*Refers to materials coded in Tables 1 and 2.

Rain erosion tests were conducted on some of the most sand erosion resistant materials. These tests were made on the whirling arm at a tip speed of 600 feet per second and a simulated rainfall equivalent to approximately 3½ inches per hour. All materials tested, except the pressure sensitive tapes, showed adequate resistance to rain erosion.

Time limitations did not permit an extensive evaluation of the effects of high and low temperatures, high humidity and solar radiation on these materials. However, a general literature review indicated that these environmental conditions do not have significantly adverse effects on polyurethanes, neoprenes and structural metals.

Based on erosion test performance, dimensional uniformity, aerodynamic contour control, system simplicity, ease of application and availability, the polyurethane film (BV 123) is considered to be the most promising material tested (Appendix IV).

CONCLUSIONS

Based on the results of this program to obtain an erosion resistant system capable of protecting helicopter rotor blades for 800 hours in a normal mission profile in desert operation, the following conclusions were reached:

1. At the present time a shelf material, Polyurethane film-BV 123*, is available which may be applied to blades in the field and can withstand approximately 250 hours of intensive desert testing. Erosion life under normal mission profile conditions would depend upon the severity of these missions (percentage of operating time spent on or near ground in a sand cloud, rotor blade tip speed, type of sand and weather conditions). Greater erosion protectors could probably be obtained with modification of shelf materials or with more exotic systems.
2. The most erosion resistant materials in each of the four categories studied were: electroformed nickel - BV 43 (metal), polyurethane BV 123 (nonmetal film), neoprene BV 197 (nonmetal liquid), and polyvinyl chloride BV 221 (nonmetal pressure sensitive tape). All of these except the polyvinyl chloride showed adequate resistance to rain erosion. Based on erosion test performance, dimensional uniformity, aerodynamic contour control, system simplicity, ease of application and availability, the polyurethane film (BV 123) is considered to be the most promising material tested (Appendix IV).
3. In general, the best nonmetals were more sand erosion resistant than the best metals.
4. The complexity of the mechanism of flat panel sand erosion was indicated by the success attained with resilient materials (polyurethanes and neoprenes) and very hard materials (silicon carbide deposited on graphite). This is further supported by the different erosion patterns at the nose and flank of whirling-arm specimens of different materials.
5. Slight modifications in any one basic material may produce significantly different erosion results.
6. A material that has good sand erosion resistance does not necessarily have adequate rain erosion resistance.

*Refers to materials coded in Tables 1 and 2.

RECOMMENDATIONS

At the inception of this program, it was planned to conduct full scale field tests only after an 800 hour erosion protection material was fully developed. The critical need to protect helicopter rotor blades now in service and the desirability of affording maximum protection for future helicopters were considered in the following recommendations:

Present

Immediately apply the polyurethane film found to be the most resistant to sand erosion in this program to rotor blades in the field and subject them to performance tests under various environments.

Implement immediate structural integrity testing of this polyurethane film and bonding system to determine the effects of extreme temperatures, aging, blade flexing and solar exposure.

Future

Exercise the option under this contract to develop and evaluate:

1. A simple field system for bonding of polyurethane film to eliminate the vacuum bagging required in the present system. Exploratory tests of several adhesive systems indicate this is feasible.
2. An improved polyurethane film with extended erosion life. Sand erosion testing and literature studies showed promising results with various additives, catalysts, chemical modifications, and radiation treatments.
3. A method for field spraying polyurethane. Spraying is currently practiced but only under controlled manufacturing conditions.
4. A pressure sensitive polyurethane tape. Technically, the production of this tape appears feasible and desirable.
5. Material combinations to afford optimum erosion properties of the system. Whirling-arm tests of polyvinyl chloride tape over stainless steel showed a 50 percent increase in erosion life over the combined individual lives.

6. The applicability of more exotic materials to provide lifetime erosion protection for future helicopter rotor blades. Impingement testing of silicon carbide produced no measurable wear after one hour.
7. Tapered systems to provide increased protection in maximum erosion areas.
8. Modification of other promising materials, such as neoprene.

INTRODUCTION

Military and company service discrepancy reports of helicopters operating in various climatic environments have frequently disclosed significant erosion of the rotor blade leading edges. In many cases, costly corrective maintenance has been required. Aircraft operating in a desert environment have been particularly hampered by sand erosion; e.g. during recent desert testing, a .020-inch 1/4 hard 301 stainless steel leading edge eroded completely through after 38 hours of operation (Reference 15).

The object of this program was to develop an erosion resistant system capable of protecting helicopter rotor blades for 800 hours in a normal mission profile in desert operations. Other desired capabilities of this system were:

1. Resistance to rain, snow, hail and dust erosion
2. Ability to withstand temperature extremes of -65° and $+165^{\circ}F$
3. Ability to withstand high humidity and solar effects
4. Ability to withstand the centrifugal force produced by the rotation of the blades without causing unbalance in the rotor blade system (Appendix IV).

This report contains the test procedures and results of Phase I of this program. The purpose of this phase was to evaluate materials that have been developed and are available at the present time in suitable quantities and forms for helicopter blade protection.

Consideration was given to field and manufacturing applications. For this reason all materials were considered in one of the following categories (listed in descending order of ease of application):

1. Pressure sensitive tapes
2. Liquid nonmetals
3. Film nonmetals
4. Metals

To accomplish the objectives of the program, activities were divided into the following areas: literature search and material selection; sand blast impingement tests; whirling-arm sand erosion tests; whirling-arm rain erosion tests; and evaluation of test results.

LITERATURE SURVEY AND MATERIAL SELECTION

An extensive literature survey was made to determine the extent of high velocity sand and rain erosion testing to date. Results of this work at the Franklin Institute and Philadelphia Free Library indicated that no systematic study of high velocity sand erosion of various materials has been conducted to date. In contrast to the lack of sand erosion test data, high velocity rain erosion information is readily available from reports such as those referenced in the bibliography.

Reports from ASTIA evaluating helicopter operations in a desert environment were reviewed. Information on the erosion protection of propeller blades from aircraft manufacturers was also obtained and studied.

As a result of this review and of contact with numerous material manufacturing companies, a total of 184 materials (53 metallic and 131 nonmetallic) were obtained for initial flat panel sand impingement tests. A general outline of these materials is as follows:

1. Metals

   A. Bonded Metal Components

      (1) Work Hardened Stainless Steels
      (2) Titanium
      (3) Beryllium Nickel
      (4) Refractory Metals
      (5) High-Nickel Alloy Steel

   B. Plated Metals

      (1) Zinc
      (2) Chrome
      (3) Electrolytic Nickel
      (4) Electroless Nickel

   C. Sprayed Deposits

      (1) Refractory Carbides
      (2) Nickel Base Alloys

D. Special Surface Treatments

(1) Thermalized Refractory Metals
(2) Anodized Aluminum

E. Metalloids

(1) Silicon Carbide

2. Nonmetals

A. Elastomers

(1) Neoprene
(2) Hypalon
(3) Polyurethane
(4) Polyvinyls
(5) Polyvinyl Fluorides
(6) Polyvinyl Chlorides
(7) Polyvinyl Acetates
(8) Polysulfides
(9) GR Rubbers
(10) Silicone Rubbers

B. Structural Resins

(1) Epoxies
(2) Polyamides

C. Pressure Sensitive Tapes

D. Ceramics

(1) Silicates
(2) Borides
(3) Silicides

E. Reinforced Systems

(1) Resin-elastomer Blends
(2) Metal-elastomer Blends
(3) Ceramic Elastomer Blends

EROSION TESTING

SAND IMPINGEMENT CABINET MODIFICATIONS

Accurate control of equipment and sand blasting technique were considered essential to the proper culling of candidate materials. Equipment for this work was obtained by modifying a standard Clemco Dry Blast Cabinet (Model AC 3636) as shown in Figure 1. A right angle steel fixture was located inside the cabinet to clamp the blast nozzle in a fixed position at any preselected height from the flat test specimens (Figure 2). An air gauge was piped to the front of the cabinet to facilitate close control of air pressure during the test period. The specimens were held in place by a magnet embedded in a rubber covered, plywood platform (Figure 3). The blast nozzle consisted of a 3/8-inch-diameter tungsten carbide orifice and a 3/16-inch-diameter air jet. Washed and dried Number 70 silica sand was used in all blast cabinet and whirling-arm tests. Sand placed in the cabinet was continuously recycled via a suction hose from the base of the sand hopper. Calibration of sand flow was made by adjusting the air to 30 psig and weighing the sand which was collected in a cloth bag. Maximum deviation of delivered weight of sand (3-1/3 lb/min) was ± 2.5 percent. New sand additions were based on performance against standard stainless steel control specimens and on sieve analyses made at regular intervals.

FLAT PANEL SAND IMPINGEMENT TEST RESULTS

Consistent results were obtained on a standard control specimen of .010-inch full hard 301 stainless steel bonded to an 0.070-inch 4130 steel backup panel. Parameters of the test were as follows:

1. 30 psig air line pressure
2. 90 degree impingement angle
3. 6 inch nozzle distance

Under these test conditions, a hole was blasted through the control specimen in 6½ ± 1 minutes. The rate of sand delivery was 3.3 ± 0.1 pounds per minute. The initial culling of all candidate materials was performed on this basis. Results of these tests are shown in Tables 1 and 2 which contain a total of 53 metallic and 131 nonmetallic specimens. This total includes various conditions of the same basic materials; e.g. 301 stainless steel sheet with various levels of hardness and thiokol with various metallic and nonmetallic fillers. Sheet

SAND IMPINGEMENT TEST

BLAST CABINET

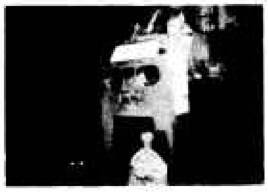


Figure 1. Exterior View of Blast Cabinet.

Figure 2. Interior View Exhibiting Method of Calibrating Sand Delivery.

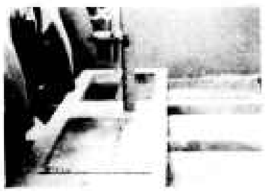


Figure 3. Interior View Exhibiting Method of Testing Flat Panels.

metals and nonmetal films were bonded to steel back-up panels. Metal platings and liquid elastomers were applied directly onto the steel backup panels. (Appendix III).

The failure time (time to blast a hole through the test specimen) varied from a minimum of 5 seconds to over 60 minutes. If a material withstood 60 minutes of blasting without failure, the test was terminated.

The typical star erosion pattern on a bonded metal specimen is shown in Figure 4. In this case the metal was reduced in section thickness before it blistered (separated from the bonding material) and a hole was formed at the center of the pattern.

Plated metal specimens eroded through evenly without any blistering (Figure 5). Titanium was the only metal that sparked during testing (Figure 16).

Typical nonmetallic erosion patterns included evenly worn holes (approximately 80 percent of the specimens), pin holes (typical of brushed liquids containing air bubbles), and burning by static electricity (approximately six specimens) (Figures 6, 7, and 8).

The addition of filler materials, aluminum oxide (Grit FFF, 36, 100), white sand (Grit 60-100) and metallic powders (200-300 M X D), to liquid thiokols, epoxies, polyurethanes, neoprenes and heat cured adhesive films did not significantly improve the sand erosion resistance of these materials. Two types of failures were noted: either the fillers were easily removed by the sand leaving small pits which deteriorated rapidly producing pin hole failures; or the matrix resin would erode from between the filler, due to its own weak resistance to erosion.

Materials which showed sand erosion resistance superior to the stainless steel control specimens under direct impingement were:

<u>Metals</u>

1. Electroformed nickel
2. Electrolytic hard chrome plate
3. Silicon carbide deposited on graphite
4. 13V-11Cr-3Al titanium
5. Refractory metal sheets - 3 types
6. Two percent beryllium - nickel alloy sheet

TEST PANEL EROSION PATTERNS

METALLIC SPECIMENS

Figure 4. "Star Effect" Typical of Bonded Metals.

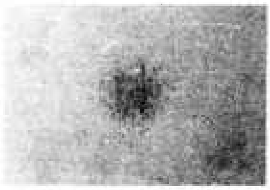


Figure 5. "Worn Hole Effect" Typical of Plated Metals.

NONMETALLIC SPECIMENS

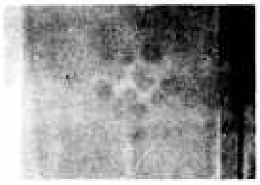


Figure 6. "Burning" Produced by Static Electricity Discharge.

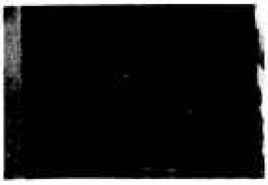


Figure 7. "Pin Hole Effect" Typical of Brushed Liquids with Bubbles.

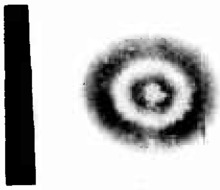


Figure 8. "Worn Hole Effect" Similar to Worn Hole Effect in Metallic Specimens.

Nonmetals

1. Films

   a. Polyurethanes - 3 types
   b. Neoprenes - 2 types
   c. Polyvinyl chloride - 1 type
   d. Modified epoxies - 3 types
   e. Nitrile phenolics - 3 types

2. Liquids

   a. Polyurethanes - 11 types
   b. Neoprenes - 2 types
   c. Polysulfide (thiokol) - 1 type

3. Pressure Sensitive Tapes

   a. Polyvinyl chlorides - 2 types

CANDIDATE MATERIALS FOR WHIRLING-ARM TESTING

Candidate materials for whirling-arm sand erosion evaluation were selected from those which showed erosion resistance superior to stainless steel in the flat panel sand impingement tests. Where several conditions or compositions of one basic material exhibited similar test results, only one was selected as being representative of this material. Since many nonmetals showed good direct impingement erosion resistance, only the superior ones were chosen for whirling-arm testing. Time limitations of the program did not permit development of an airfoil configuration of some materials, such as silicon carbide, which displayed excellent impingement test results.

The candidate materials for whirling-arm sand erosion testing were:

Metals

1. Nickel - electroformed and bonded (BV 42 and 43)*
2. Hard chrome plate - direct electrolytic plate (BV 35)
3. 13V-11Cr-3Al titanium - annealed, bonded sheet (BV 10)
4. Unalloyed molybdenum - annealed, bonded sheet (BV 26 and 27)
5. Two per cent beryllium-nickel - annealed, bonded sheet (BV 18)

Nonmetals

1. Films

    a. Polyurethanes (BV 123 and BV 124)
    b. Neoprenes (BV 197 and BV 204)
    c. Polyvinyl chloride (BV 114)
    d. Modified epoxy (BV 134)
    e. Phenolics-nitrile (BV 126 and BV 128)

2. Liquids

    a. Polyurethanes (BV 164, 165, 167, 168, 170, 172, and 173)
    b. Neoprenes (BV 41 and 44)
    c. Polysulfide (thiokol) (BV 148)

3. Pressure Sensitive Tapes

    a. Polyvinyl chloride - 2 types (BV 221 and 222)

The whirling-arm specimens consisted of the various test materials attached to 10-inch steel leading edge sections of a helicopter rotor blade spar. The nonmetal liquids and tapes and chrome plate were applied directly to the leading edge sections. All metals (except the chrome plate) and the nonmetal films were bonded to the leading edge sections.

All metal specimens were approximately .010-inch thick. Stainless steel and electroformed nickel in this gage are presently being used for nose caps of production helicopter blades.

* Refers to materials coded in Tables 1 and 2.

TABLE 1

FLAT PANEL SAND IMPINGEMENT TEST RESULTS - METALS

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
	BONDED SHEET METALS			
1.	301 SS Extra Hard	.010	6.4	0.64
2.	301 SS Full Hard (Control)	.010	6.0-7.0	0.6-0.7
3.	301 SS 3/4 Hard	.010	6.2	0.62
4.	301 SS 1/2 Hard	.010	6.2	0.62
5.	301 SS 1/4 Hard	.010	4.5	0.45
6.	301 SS Annealed	.005	1.5	0.30
7.	17-7PH Condition C	.010	6.5	0.65
8.	Titanium 6Al-4V Annealed	.009	4.2	0.47
9.	Titanium 6Al-4V Solution Treated and Aged	.009	4.1	0.45
10.	Titanium 13V-11Cr-3Al Annealed	.010	6.6	0.66
11.	Titanium 13V-11Cr-3Al Cold Rolled and Aged	.010	5.8	0.58
12.	Titanium 13V-11Cr-3Al Solution Treated and Aged	.010	5.5	0.55
13.	Aluminum 2024-T3	.012	4.1	0.34
14.	Aluminum 2024-T3	.019	6.5	0.34
15.	Aluminum 2024-T3	.062	23	0.37
16.	Beryllium Nickel 1/4 Hard	.010	6.0	0.60
17.	Beryllium Nickel Heat Treated	.010	4.8	0.48
18.	Beryllium Nickel Annealed	.010	6.8	0.68
19.	Beryllium Nickel Annealed and Tempered	.010	6.1	0.61

TABLE 1 (Continued)

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
20.	Molybdenum (Arc-Cast)	.010	10.5	1.10
21.	Molybdenum + 1/2% Ti	.010	11.0	1.10
22.	Molybdenum + 1/2% Ti	.010	13.0	1.30
23.	Tungsten	.007	2.1	0.30
24.	Tantalum	.010	8.9	0.89
25.	Columbium	.009	6.6	0.73
26.	Molybdenum (Powder Metal)	.012	14.4	1.20
27.	Molybdenum (Arc-Cast)	.012	13.2	1.10
28.	Molybdenum + Zirconium + Titanium	.011	10.7	0.98
29.	Tantalum Not Annealed	.010	10.0	1.00
30.	Tantalum Annealed	.010	8.5	0.85
31.	4340 Hardened and Tempered	.050	10.0**	1.00
32.	18% Nickel Steel	.080	10.0**	1.00
	PLATED METALS			
33.	Zinc Plate	.0013	0.33	0.25
34.	Chrome Plate	.0005	0.50	1.00
35.	Chrome Plate	.003	3.00	1.00
36.	Chrome Plate	.004	3.20	0.80
37.	Chrome Plate	.0015	.83	0.55
38.	Hard Nickel Plate	.002	1.40	0.70
39.	Sulfuric Nickel Plate	.002	2.00	1.00
40.	Electroless Nickel as Plated	.005	.50	0.10
41.	Electroless Nickel Heat Treated 1150°F One Hour	.005	1.00	0.20
42.	Electroformed Nickel (on SS Mandrel)	.013	10.40	0.80
43.	Electroformed Nickel (on Plastic Mandrel)	.013	12.50	0.96
44.	Electrolyzed Chrome	.0002	.81	0.41

TABLE 1 (Continued)

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
	PROPRIETARY SPECIAL SURFACE TREATMENTS OF METALS			
45.	Molybdenum + 1/2% Ti with Hardened Surface	.021	21.0	1.00
46.	2024 Aluminum with hard Anodic Surface Treatment	.0025	.15	0.006
47.	2024 Aluminum with hard Anodic Surface Treatment	.003	.05	0.002
	SPRAYED METAL COATINGS			
48.	Tungsten Carbide	.011	4.2	0.38
49.	Nickel-Chrome Alloy	.010	2.0	0.20
50.	Cobalt Base Alloy	.010	1.66	0.13
51.	Nickel Base Alloy	.011	4.40	0.40
52.	Nickel Base Alloy	.004	2.5	0.61
	METALLOID			
53.	Silicon Carbide	.015	60.0*	No Wear

* No Failure

** .010 in. eroded.

TABLE 2

FLAT PANEL SAND IMPINGEMENT TEST RESULTS - NONMETALS

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
		FILMS		
100.	Buna N-Nylon Cloth	.013	14.0	1.1
101.	Neoprene	.012	2.2	0.2
102.	Silicone Rubber on Glass Cloth	.033	1.1	0.3
103.	Silicone Foam Rubber	.093	3.3	0.3
104.	Black Gr Foam Rubber	.064	5.0	0.1
105.	Gr Type 1 Black Rubber	.094	33.0	0.4
106.	Neoprene on Airplane Cloth	.012	1.0	0.5
107.	Neoprene on Nylon Cloth	.013	2.7	1.2
108.	Neoprene Sheet	.031	60.0*	No Wear
109.	Neoprene Sheet	.031	60.0*	No Wear
110.	Rubber & Phenolic (Asbestos Filler)	.250	5.0*	1.0
111.	Rubber & Cork Filler	.020	4.0	0.1
112.	Silicone Rubber (Asbestos Filler)	.250	1.3	0.0
113.	Rubber & Phenolic (Asbestos Filler)	.250	5.0*	0.6
114.	Polyvinyl Chloride	.015	70.0	4.0
115.	Polyvinyl Acetate	.003	4.1	1.6
116.	Polyvinyl Fluoride	.004	1.0	0.3
117.	Polyvinyl Fluoride	.008	2.0	0.3
118.	Polyvinyl	.015	15.0	1.0
119.	Polyvinyl	.035	12.0	0.4
120.	Polyvinyl	.015	11.2	0.7
121.	Polyvinyl	.020	12.5	0.6
122.	Polyvinyl	.020	40.7	2.0
123.	Polyurethane	.031	60.0*	No Wear
124.	Polyurethane	.031	60.0*	No Wear

TABLE 2 (Continued)				
BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
125.	Polyurethane	.106	60.0*	No Wear
126.	Phenolic and Nitrile	.016	37.0	2.3
127.	Phenolic and Nitrile	.012	36.0	3.0
128.	Phenolic and Nitrile	.017	55.0	3.5
129.	Phenolic and Nitrile	.009	8.0	0.8
130.	Phenolic and Nitrile	.023	45.0*	No Wear
131.	Modified Epoxy	.016	64.0*	4.0+
132.	Modified Epoxy	.012	4.1	0.4
133.	BV No. 132 and Aluminum Oxide	.035	3.0	0.1
134.	Modified Epoxy	.017	60.0*	3.5+
135.	BV No. 134 and Aluminum Oxide	.035	15.0	0.4
136.	Modified Epoxy	.017	68.0*	4.0+
137.	BV No. 136 and Aluminum Oxide	.037	11.2	0.3
138.	Teflon	.010	34.2	3.4
139.	Teflon	.010	4.3	0.4
140.	Teflon	.010	4.5	0.4
141.	Epoxy-Glass Laminate	.077	1.2	0.0
142.	Epoxy-Glass Laminate	.028	2.1	0.0
		LIQUIDS		
143.	Nitrile Rubber	.032	60.0*	10.0
144.	Ethylene Propylene Rubber	.024	72.1*	18.0
145.	Polyurethane	.030	63.7*	2.1+
146.	Polyurethane	.020	37.7	1.9
147.	Polyurethane	.025	45.0	1.9
148.	Polysulfide	.020	27.3	1.35
	BV No. 148 with the following metal fillers at a one to one ratio - metals (200 to 300M) added after catalyzing and mixing.			

TABLE 2 (Continued)

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
149.	BV No. 148 & Aluminum Oxide FFF	.027	20.2	0.74
150.	BV No. 148 & Aluminum Oxide 36G	.037	10.0	0.27
151.	BV No. 148 & Aluminum Oxide 100G	.013	3.0	0.23
152.	BV No. 148 & Columbium Carbide Powder	.025	2.4	0.9
153.	BV No. 148 & Columbium Metal Powder	.030	2.1	0.7
154.	BV No. 148 & Molybdenum Disulfide Powder	.031	30.1	0.97
155.	BV No. 148 & Vanadium Carbide Powder	.029	30.5	1.03
156.	BV No. 148 & Tungsten Metal Powder	.026	36.4	1.4
157.	BV No. 148 & Tungsten Carbide Powder	.026	44.2	1.7
158.	BV No. 148 & Tantalum Carbide Powder	.012	16.6	1.33
159.	BV No. 148 & Chromium Carbide Powder	.026	28.1	1.10
160.	BV No. 148 & Chrome Metal Powder	.033	25.7	0.75
161.	BV No. 148 & Silicon Nitride Powder	.019	7.1	0.35
162.	Chlorosulfonated Polyethylene	.070	65.0	0.9
163.	BV No. 138 and Aluminum Oxide	.042	6.0	0.1
164.	Polyurethane and Moca	.021	60.0	PH.**
165.	Polyurethane and Vinyl	.022	90.0	PH.
166.	Polyurethane and Polyvinyl	.050	17.0	PH.
167.	Polyurethane and Moca	.021	60.0	PH.
168.	Polyurethane and Vinyl	.025	71.0	PH.
169.	Polyurethane and Polyvinyl	.070 (Foamed)	27.5	PH.

TABLE 2 (Continued)

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
170.	Polyurethane	.023	60.0	PH.
171.	Polyurethane	.013	60.0	PH.
172.	Polyurethane	.025	45.0	1.9
173.	Polyurethane	.014	60.0	PH.
174.	Polyurethane	.040	35.0	PH.
	BV No. 174 and the following metal fillers added after catalyzing and mixing at one-to-one ratio.			
175.	BV No. 174 & Columbium Carbide Powder	.040	32.7	0.81
176.	BV No. 174 & Columbium Metal Powder	.026	9.2	0.36
177.	BV No. 174 & Molybdenum Disilicide Powder	.023	10.0	0.35
178.	BV No. 174 & Tantalum Carbide Powder	.028	23.00	0.8
179.	BV No. 174 & Silicon Nitride Powder	.019	7.1	0.35
180.	BV No. 174 & Vanadium Carbide Powder	.022	13.0	0.6
181.	BV No. 174 & Tungsten Metal Powder	.025	22.9	0.9
182.	BV No. 174 & Tungsten Carbide Powder	.032	25.1	0.8
183.	Polyurethane	.020	9.1	0.43
184.	BV No. 183 & Al_2O_3 (100/100 Pts.)	.030	10.1	0.33
185.	Epoxy	.020	1.2	0.0
186.	Modified Epoxy	.025	12.5	0.5
	BV No. 186 with following fillers added after catalyzing and mixing at one-to-one ratio			
187.	BV No. 186 & Aluminum Oxide (FFF)	.038	11.0	0.3

TABLE 2 (Continued)				
BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
188.	BV No. 186 & Aluminum Oxide (36G)	.037	25.1	0.7
189.	BV No. 186 & Aluminum Oxide (100G)	.035	0.9	0.0
190.	BV No. 186 & 5 Pts. Liquid Nylon	.029	11.3	0.38
191.	BV No. 186 & 10 Pts. White Sand	.047	12.5	0.26
192.	Epoxy & Polyamide (50:50)	.095	3.1	0.0
193.	BV No. 192 Aluminum Oxide (FFF)	.027	1.1	0.0
194.	BV No. 192 & Aluminum Oxide (100G)	.035	2.1	0.0
195.	BV No. 192 & Aluminum (36G)	.037	2.2	0.0
196.	Liquid Neoprene (6 coats)	.010	8.0	0.8
197.	BV No. 196 (12 Coats)	.021	70.0*	3.3+
198.	BV No. 196 (18 Coats)	.036	60.0*	1.7+
199.	BV No. 196 (6 coats) & Al_2O_3 (FFF)	.042	4.5	0.1
200.	Liquid Neoprene (6 coats)	.025	20.0	0.8
201.	BV No. 200 (9 coats)	.035	42.0	1.2
202.	Liquid Neoprene	.210	25.3	1.2
203.	Liquid Neoprene	.025	19.0	1.3
204.	Liquid Neoprene	Q017	50.0	2.8
205.	Liquid Neoprene	.030	21.1	0.8
206.	Epoxy-Amide	.020	2.2	0.0
207.	BV No. 206 & Al_2O_3 (FFF)	.025	8.3	0.3
208.	Al_2SiO_3 Ceramic	.012	0.1	0.0
209.	Na_2SiO_3 Ceramic	.010	0.1	0.0

TABLE 2 (Continued)

BV No.	Material	Thickness (in.)	Failure Time (min.)	Erosion Rate (min./.001 in.)
210.	Al_2SiO_3 Ceramic	.008	2.0	0.2
211.	Pb_2SiO_3 Ceramic	.016	0.1	0.0
212.	Na_2SiO_3 Ceramic	.014	0.1	0.0
213.	Na_2SiO_3 Ceramic	.010	0.1	0.0
214.	Nylon	.004	4.1	1.0
215.	Na_2SiO_3 Ceramic Neoprene Coated	.014	25.0	1.6
216.	Al_2SiO_3 Ceramic-Neoprene Coated	.019	20.0	1.0
217.	$NaAlSiO_3$ Ceramic-Neoprene Coated	.020	6.0	0.7
218.	Na_2SiO_3 Ceramic-Neoprene Coated	.020	20.0	1.0
219.	Polyvinyl Chloride	.010	13.3	1.3
220.	Polyvinyl Chloride	.010	13.1	1.3
221.	Polyvinyl Chloride	.020	34.0	1.7
222.	Polyvinyl Chloride	.010	22.0	2.2
223.	Polyvinyl Chloride	.005	1.0	0.2

* No failure.

** Pin holes in specimen.

Nonmetal films and tapes were tested in the thickness available in production quantities. These ranged from .010 inch (polyvinyl chloride pressure sensitive tape) to .031 inch (polyurethane film).

Liquid polyurethanes and polysulfides were mixed and then applied to the leading edge sections in a viscous state in one coat. Target thickness was .015/.020 inch and actual thicknesses varied from .008 inch to .030 inch.

Liquid neoprene specimens were prepared by applying ten successive brush coats to the leading edge sections (approximately .015 inch total). This thickness had provided optimum results in flat panel impingement tests and Sahara Desert tests (Reference 11, Bibliography). Thicker brush coatings were also considered impractical because of prolonged application and cure times (Appendix III).

WHIRLING-ARM EQUIPMENT AND STANDARDIZATION - SAND EROSION

The whirling-arm rig with accessory power and control units is shown in Figures 9 through 17. Power was supplied by a 40 horsepower electric motor to a 2,500 psi hydraulic pump. A hydraulic motor applied torque to the rotor shaft which rotated the 5-foot arm (center-mounted). Shaft rpm and unbalance were monitored by electronic units.

Test materials were bonded to replaceable steel leading edge sections, which comprised the outboard 10-1/8 inches of each end of the arm. One of these replaceable leading edge sections is shown in Figure 14.

The test sand was the same as the Number 70 washed and dried silica sand used in the sand impingement tests. The sand was placed in 8 bins, equally spaced around the perimeter of the rig (Figure 16). Each contained 3-1/8 pounds of sand which emptied by gravity through a 5/32-inch bottom orifice in approximately 13 minutes. These orifices were plugged with wooden pins which were removed when the arm reached the desired speed. Calibration runs were made with .009-inch full hard 301 stainless steel leading edge specimens on either end of the arm.

WHIRLING-ARM SAND EROSION TEST

TEST RIG ASSEMBLY AND INSTRUMENTATION

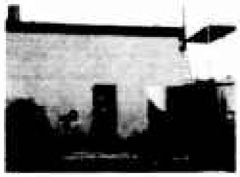


Figure 9.
Test Rig Assembly and Instrumentation.

Figure 10.
Top View of Test Rig.

Figure 11.
Test Rig Hydraulic Power Supply.

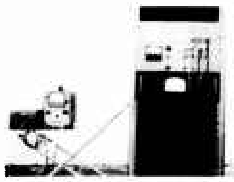


Figure 12.
Instrumentation.

Figure 13.
Test Rig Lubrication System.

Figure 14.
Whirling-Arm Blade.

Figure 15.
Sand Hopper - Eight in Operation Simultaneously.

Figure 16.
Test in Operation - Titanium.

Figure 17.
Wear on Whirling-Arm Blade Evident After Extensive Testing.

Consistent results were obtained with the following parameters:

a. Arm tip speed, 600 feet per second (approximately blade tip speed of hovering helicopters)
b. Sand bin orifices, 6 inches above arm
c. Sand bin orifices, 4 inches in from the outboard ends of the arm

For the purpose of this report one run is defined as a test cycle in which 25 ± 0.1 pounds of sand were dropped from 8 bins in 13 ± 1 minutes on the test specimens, while the arm was rotating at a tip speed of 600 feet per second (Figure 20). Half runs consisted of 12.5 pounds of sand dropped from 8 bins in 6½ minutes on the test specimens whirling at the same tip speed (Figure 19). Quarter runs consisted of 6¼ pounds of sand dropped from 8 bins in 3¼ minutes on the test specimens whirling at the same tip speed (Figure 18).

Half runs and quarter runs were used to determine the initial failures of test specimens when necessary. On each test run, a control specimen of .009-inch thick bonded full hard 301 stainless steel sheet was mounted on the arm opposite the test specimen (Figure 14).

Control specimens tested for one run, consistently produced a triangular erosion pattern through the stainless steel, through the bonding material, and into the steel leading edge backup. Reproduction of this erosion pattern throughout the test program indicated that the test was under control.

Several control specimens were also tested under half run conditions. Results indicated that initial erosion failure occurred in this time.

WHIRLING-ARM SAND EROSION TEST RESULTS

Each candidate material was tested for one run. Specimens which survived one run were exposed to successive runs until the materials were eroded through. Results are tabulated in Tables 3 and 4, (Pages 37 - 47).

The materials exhibiting the most resistance to sand erosion under these conditions are listed below by categories:

MATERIAL	THICKNESS (in.)	NUMBER OF RUNS TO FAILURE
METALS		
Electroformed Nickel BV 43	.011	2
Molybdenum - Arc-Cast BV 27	.010	1½
NONMETALS		
Tapes		
Polyvinyl chloride BV 221	.020	1/2
Polyvinyl chloride BV 222	.010	1/4
Liquids		
Neoprene BV 197	.021	5
Neoprene BV 204	.015	4
Films		
Polyurethane BV 123	.031	8
Polyurethane BV 124	.031	6
CONTROL*		
Full Hard 301 Stainless Steel	.009	1/2

Test results on 301 stainless steel indicated that the erosion resistance is not dependent upon hardness and that erosion rate is constant for the range of section thickness tested. Erosion resistance of full hard, 1/4 hard, and annealed 301 of equal thicknesses was identical.

* For comparison

Failure patterns of .032-inch 301 after three runs, .020-inch 301 after two runs, and .009-inch 301 after one run were all similar in appearance (Figures 23, 24, and 20 respectively).

Whirling-arm sand erosion failure patterns occurred at different locations on the test specimens. The electroformed nickel and arc-cast molybdenum specimens eroded on the nose or apex of the air foil configuration (Figure 29). The nonmetal films and tapes exhibited a wear pattern on the flank of the specimen approximately one inch from the nose as measured along the chord line (Figures 33 and 35). Liquid neoprene specimens failed by pitting erosion on the nose. (Figure 31).

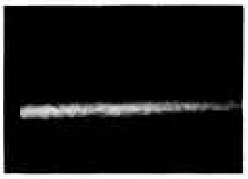
Since the best polyvinyl chloride tape resisted erosion on the nose and the 301 full hard stainless steel showed light erosion on the flanks of the specimens after testing, a combination specimen of these two materials was tested. Separately, each material had a wear life of <u>1/2 run</u>; however, the combination specimen, with tape over the stainless, exhibited a wear life of <u>1-1/2 runs</u> - Appendix I, Figures 50 and 51).

Both the sand impingement and whirling-arm tests revealed that the application procedures for liquid coatings significantly affected the sand erosion resistance of the specimens. Small air bubbles entrapped in the liquid and pin holes allowed premature erosion of the base plate in these areas. This was particularly true of the liquid neoprenes and polyurethanes (Figure 7).

WHIRLING-ARM RAIN EROSION TESTING

Rain erosion tests were conducted on the whirling-arm sand test rig with the 8 sand bins removed and a single water spray nozzle mounted 5 feet above the center of the blade. Spraying System Company, Bellwood, Illinois, designed the 1/4 gg-10 nozzle which delivered a water spray equivalent to $7\frac{1}{4} \pm \frac{1}{2}$ inches of average rainfall over the entire blade area (5-foot-diameter circle). Flat petri dishes placed at the outboard ends of the stationary arm measured an equivalent of $3\frac{1}{2}$ inches per hour of rainfall.

WHIRLING-ARM SAND EROSION TEST RESULTS OF 301SS*



Full Hard.
Thickness, .009 In.
Duration of 1/4 Run, 3-1/4 Min.
Bonded.

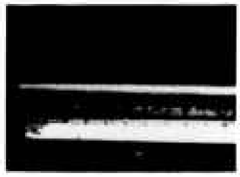
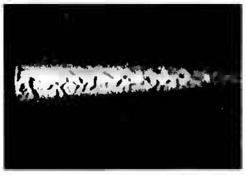
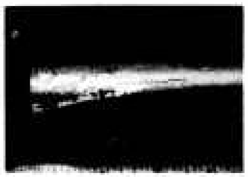


Figure 18. BV 121-2



Full Hard.
Thickness, .009 In.
Duration of 1/2 Run, 6-1/2 Min.
Bonded.

Figure 19. BV 110-2



Full Hard.
Thickness, .009 In.
Duration of 1 Run, 13 Min.
Bonded.

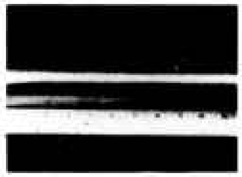
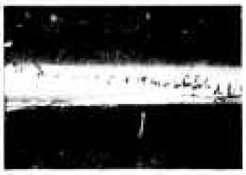
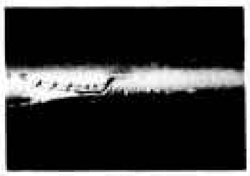


Figure 20. BV 97-2



1/4 Hard.
Thickness, .010 In.
Duration of 1 Run, 12-1/2 Min.
Bonded.

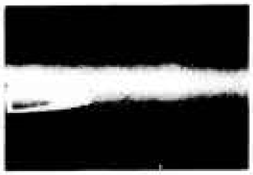
Figure 21 BV 135-5



1/4 Hard.
Thickness, .020 In.
Duration of 2 Runs, 24-3/4 Min.
Bonded.

Figure 22 BV 138-5

* See Tables 3 and 4



1/4 Hard.
Thickness, .032 In.
Duration of 3 Runs, 37-1/2 Min.
Bonded.

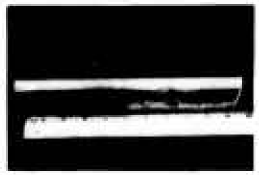
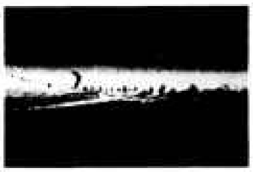
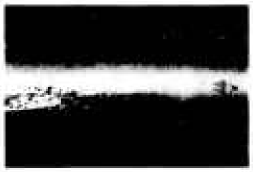


Figure 23 BV 139-5



Annealed.
Thickness, .020 In.
Duration of 2 Runs, 24-1/2 Min.
Bonded.

Figure 24 BV 140-6



Annealed.
Thickness, .034 In.
Duration of 3 Runs, 37-1/4 Min.
Bonded.

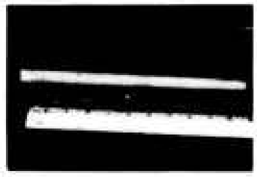
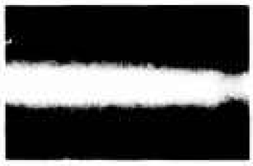


Figure 25 BV 141-6



Bell.
1/4 Hard.
Thickness, .020 In.
Duration of 1 Run, 12-1/4 Min.
Bonded.

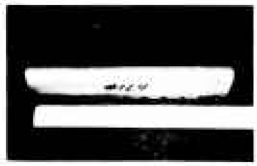


Figure 26 BV 164-5

Bell.
1/4 Hard.
Thickness, .020 In.
Duration of 1-1/2 Runs, 17-3/4 Min.
Bonded.

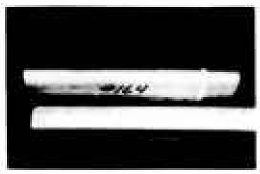


Figure 27 BV 164-5

WHIRLING-ARM SAND EROSION TEST RESULTS*
TYPICAL SAND EROSION PATTERNS

Metal

Figure 28

BV 43
Electroformed Nickel
Duration of 1 Run

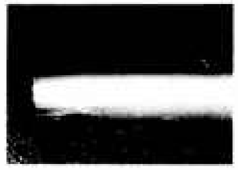


Figure 29

BV 43.
Electroformed Nickel
Duration of 2 Runs

Nonmetals

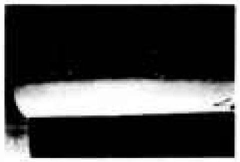


Figure 30

BV 197.
Liquid Neoprene
Duration of 1 Run

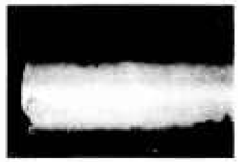


Figure 31

BV 197.
Liquid Neoprene
Duration of 5 Runs

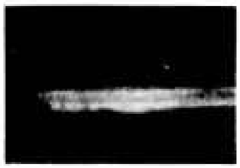


Figure 32

BV 123.
Polyurethane Film.
Duration of 1 Run.

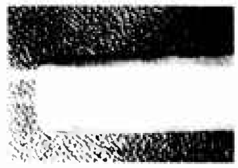


Figure 33

BV 123.
Polyurethane Film
Duration of 8 Runs.

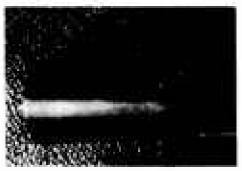


Figure 34

BV 221
Polyvinyl Chloride
Pressure Sensitive Tape.
Duration of 1/4 Run.

Figure 35

BV 221
Polyvinyl Chloride
Pressure Sensitive Tape.
Duration of 1/2 Run.

* See Tables 1 and 2

Water was pumped from a shallow well at approximately 57°F and 54 psig. Blade tip speed was maintained at 600 feet per second during all tests.

WHIRLING-ARM RAIN EROSION TEST RESULTS

Several materials which indicated high resistance to sand erosion on the whirling-arm rig were tested under the water spray to evaluate their relative resistance to rain erosion. Based on the tests performed, polyurethane films were rated good to excellent; neoprene and stainless steel were rated excellent; and pressure sensitive tapes were rated poor.

Data and photographic documentation of test results have been compiled in Table 5 and Appendix II, respectively.

In general, the test data obtained correlated well with rain erosion results published in WADC Technical Report 53-185. (Reference 3, Bibliography).

CORRELATION OF TEST RESULTS AND SERVICE EXPERIENCE

Records of past service experience with various materials were reviewed. A comparison of this data and the test results obtained in this program for various materials are shown in Table 6.

During recent intensive desert testing at Yuma, Arizona, stainless steel rotor blades (.020-inch 1/4 Hard 301) were eroded through in approximately 40 hours (Reference 15, Bibliography). The whirling-arm sand erosion test life of this material (BV 5) was approximately 1/6 that of the most erosion resistant polyurethane film (BV 123). Projection of these test results indicates that this polyurethane film would withstand approximately 250 hours of intensive desert testing. Erosion life under normal mission profile conditions would depend upon the severity of these missions (percentage of operating time spent on or near ground in sand cloud, rotor blade tip speed, type of sand, and weather conditions).

TABLE 3

WHIRLING-ARM SAND EROSION TEST RESULTS - METALS

BV No.	Materials	Thickness (in.)	Weight (g.) Before	Weight (g.) After	Test Run (qt.)	Comments
12-42*	Electroformed Nickel	.009	420.0	415.5	1	Wrinkled Skin
Control**		.009	423.5	418.5	1	
11-42	Electroformed Nickel	.009	419.5	415.0	1	Slightly Eroded
Control		.009	522.0	517.0	1	
23-	Electroformed Nickel	.014	437.5	433.0	1	No Apparent Damage
Control		.009	509.5	505.0	1	
23-	Electroformed Nickel	—	433.0	428.0	2	Eroded Through
Control		.009	422.0	416.5	1	
14-43	Electroformed Nickel	.011	418.0	413.5	1	No Apparent Damage
Control		.009	439.0	434.5	1	
14-43	Electroformed Nickel	—	413.0	408.5	2	Eroded Through
Control		.009	421.0	417.0	1	
24-	Electroformed Nickel	.009	404.5	399.5	1	Eroded Through
Control		.009	413.5	408.0	1	
13-43	Electroformed Nickel	.010	418.5	413.0	1	No Apparent Damage
Control		.009	423.5	418.0	1	

TABLE 3 (Continued)						
BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
13-43	Electroformed Nickel	—	413.0	408.0	2	Eroded Through
Control		.009	419.5	414.5	1	
127-42	Electroformed Nickel	.009	431.0	426.0	1	Eroded Through
Control		.009	425.0	418.5	1	
124-	Electroformed Nickel	.009	412.5	406.5	1	Eroded Through
Control		.009	419.0	413.0	1	
128-42	Electroformed Nickel	.011	426.5	421.0	1	No Apparent Damage
Control		.009	421.5	416.0	1	
128-42	Electroformed Nickel	—	421.0	418.5	1½	No Apparent Damage
Control		.009	421.0	418.0	1½	
135-5	301 ¼ Hard Stainless Steel	.010	408.5	403.0	1	Eroded Through
Control		.009	423.5	418.0	1	
141-6	301 Annealed Stainless Steel	.034	562.0	556.5	1	No Apparent Damage
Control		.009	435.5	430.5	1	
141-6	301 Annealed Stainless Steel	—	556.5	551.0	2	No Apparent Damage
Control		.009	437.0	432.5	1	
141-6	301 Annealed Stainless Steel	—	551.0	545.5	3	Eroded Through
Control		.009	432.0	427.5	1	

TABLE 3 (Continued)

BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comment
			Before	After		
140-6	301 Annealed Stainless Steel	.020	489.5	483.5	1	Wrinkled
Control		.009	428.5	423.0	1	
140-6	301 Annealed Stainless Steel	—	483.5	478.5	2	Eroded Through
Control		.009	516.5	511.5	1	
139-5	301¼ Hard Stainless Steel	.032	552.0	546.5	1	No Apparent Damage
Control		.009	423.5	417.5	1	
139-5	301¼ Hard Stainless Steel	—	546.5	541.0	2	No Apparent Damage
Control		.009	419.5	414.5	1	
139-5	301¼ Hard Stainless Steel	—	541.0	535.5	3	Eroded Through
Control		.009	431.5	426.5	1	
138-5	301¼ Hard Stainless Steel	.020	483.5	478.0	1	Slightly Wrinkled
Control		.009	423.5	417.5	1	
138-5	301¼ Hard Stainless Steel	—	478.0	472.5	2	Eroded Through
Control		.009	428.5	423.5	1	
164-5	301¼ Hard Stainless Steel	.020	467.0	462.0	1	No Apparent Damage
Control		.009	424.0	419.0	1	
164-5	301¼ Hard Stainless Steel	.020	462.0	459.5	1½	Eroded Through
Control		.009	416.0	413.5	1½	

	TABLE 3 (Continued)					
BV No.	Materials	Thickness (in.)	Weight (g.) Before	After	Test Run (qt.)	Comments
163-5	301¼ Hard Stainless Steel	.020	470.0	465.5	1	No Apparent Damage
Control		.009	430.0	425.0	1	
144-2	301 Full Hard Stainless Steel	.009	438.5	433	1	Eroded Through
Control		.009	431.0	425.5	1	
16-10	113V11Cr3A1 Titanium	.012	420.0	418.0	1	Wrinkled
Control		.009	424.5	421.5	1	
16-10	13V11Cr3A1 Titanium	.012	417.5	414.5	2	Eroded Through
Control		.009	422.5	417.5	1	
15-10	13V11Cr3A1 Titanium	.012	406.5	402.5	1	Eroded Through
Control		.009	411.0	406.5	1	
125-10	13V11Cr3A1 Titanium	.012	421.0	418.0	1	Eroded Through
Control		.009	426.0	420.5	1	
151-	Chrome Plate on Copper	(Cr).009	402.0	395.5	1	Eroded Through
Control		.009	425.0	420.0	1	
126-18	Beryllium Nickel	.010	444.5	439.0	1	Eroded Through
Control		.009	432.0	426.5	1	
21-18	Beryllium Nickel	.010	446.5	441.5	1	Eroded Through
Control		.009	417.0	412.5	1	

TABLE 3 (Continued)

BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
187-27	Molybdenum Arc Cast	.001	455.5	452.0	1	Slightly Damaged (1 pit)
Control		:009	421.0	416.0	1	
189-26	Molybdenum Powder Metal	.009	447.5	443.0	1	Eroded Through
Control		.009	419.5	414.5	1	
106-2	301 F.H. SS Etched Before Bonding	.009	433.0	428.0	1	Eroded Through
Control		.009	436.0	431.0	1	
9-35	Chrome Plate	.009	378.0	373.0	1	Eroded Through
Control		.009	423.5	418.0	1	

* Number preceding dash refers to whirling-arm specimen; number following dash refers to materials coded in Tables 1 and 2.

** All controls were full hard 301 stainless steel.

TABLE 4

WHIRLING-ARM SAND EROSION TEST RESULTS - NONMETALS

BV No.	Materials	Thickness (in.)	Weight (g.) Before	Weight (g.) After	Test Run (qt.)	Comments
40-126*	Nitrile-Phenolic	.045	420.5	418.5	1	No Apparent Damage
Control**		.009	422.5	417.5	1	
40-126	Nitrile-Phenolic	-	418.5	416.5	2	Eroded Through
Control		.009	434.0	428.5	1	
41-204	Neoprene	.015	388.5	388.4	1	Light Erosion
Control		.009	422.5	417.5	1	
41-204	Neoprene	-	388.4	387.5	2	Light Erosion & Edge Damage
Control		.009	434.0	428.5	1	
41-204	Neoprene	-	387.5	387.5	3	Mild Erosion & Edge Damage
Control		.009	425.5	420.5	1	
41-204	Neoprene	-	387.5	386.5	4	Heavy Erosion (Not Through) & Edge Damage
Control		.009	423.5	418.5	1	
47-222	Polyvinyl Chloride	.010	381.5	380.0	1	Eroded Through
Control		.009	441.0	437.5	1	
48-221	Polyvinyl Chloride	.020	372.5	369.2	1	Eroded Through
Control		.009	440.5	436.0	1	
45-124	Polyurethane	.031	400.5	400.1	1	No Apparent Damage
Control		.009	439.0	435.0	1	

TABLE 4 (Continued)						
BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
45-124	Polyurethane	-	400.0	399.0	2	No Apparent Damage
Control		.009	481.5	414.0	1	
45-124	Polyurethane	-	399.0	399.0	3	No Apparent Damage
Control		.009	434.0	429.0	1	
45-124	Polyurethane	-	398.0	397.5	4	Mild Edge Erosion
Control		.009	424.5	419.5	1	
45-124	Polyurethane	-	398.0	397.5	5	Mild Edge Erosion
Control		.009	424.5	419.5	1	
45-124	Polyurethane	-	397.5	396.5	6	Mild Erosion, Edge Abraded Through
Control		.009	518.0	513.0	1	
43-109	Neoprene	.031	392.5	390.0	1	Slight Edge Erosion
Control		.009	419.5	415.0	1	
43-109	Neoprene	-	390.0	386.0	2	Eroded Through
Control		.009	420.0	414.5	1	
46-123	Polyurethane	.031	398.5	398.5	1	No Apparent Damage
Control		.009	426.5	422.5	1	
46-123	Polyurethane	-	398.0	398.0	2	No Apparent Damage
Control		.009	431.0	427.0	1	

TABLE 4 (Continued)						
BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
46-123	Polyurethane	-	398.0	397.5	3	No Apparent Damage
Control		.009	420.5	416.0	1	
46-123	Polyurethane	-	397.5	397.0	4	No Apparent Damage
Control		.009	427.5	422.5	1	
46-123	Polyurethane	-	395.5	396.5	5	No Apparent Damage
Control		.009	439.5	435.0	1	
46-123	Polyurethane	-	396.5	396.0	6	No Apparent Damage
Control		.009	433.0	428.0	1	
46-123	Polyurethane	-	396.0	395.5	7	Light Edge Erosion
Control		.009	437.0	432.0	1	
46-123	Polyurethane	-	395.5	394.5	8	Light Erosion, Edge Abraded Through
Control		.009	427.0	421.5	1	
41-114	Polyvinyl Chloride	.015	390.0	387.5	1	Eroded Through
Control		.009	420.0	416.5	1	
42-108	Neoprene	.054	416.5	414.5	1	Slight Edge Erosion
Control		.009	422.0	417.0	1	
42-108	Neoprene	-	414.0	411.0	2	Eroded Through
Control		.009	425.0	421.5	1	

TABLE 4 (Continued)						
BV No.	Materials	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
44-197	Neoprene	.021	397.5	397.5	1	No Apparent Damage
Control		.009	424.0	419.5	1	
44-197	Neoprene	-	397.5	397.0	2	Light Erosion
Control		.009	419.0	414.0	1	
44-197	Neoprene	-	396.0	396.0	3	Light Erosion & Edge Damage
Control		.009	438.0	433.5	1	
44-197	Neoprene	-	396.0	396.0	4	Mild Erosion & Edge Damage
Control		.009	421.5	417.0	1	
44-197	Neoprene	-	395.0	395.0	5	Heavy Erosion (Not Through) & Edge Damage
Control		.009	418.0	413.5	1	
56-221	Polyvinyl Chloride	.020	370.0	368.5	½	Edge Abraded Through 1 in.
Control		.009	410.0	407.5	½	
55-222	Polyvinyl Chloride	.010	381.0	380.0	½	Abraded Through 3 in.
Control		.009	508.0	505.0	½	
54-126	Phenolic & Nitrile	.015	383.5	380.0	1	Abraded Through 3 in.
Control		.009	429.5	524.5	1	

TABLE 4 (continued)

BV No.	Material	Thickness (in.)	Weight (g) Before	Weight (g) After	Test Run (qt.)	Comments
66-221	Polyvinyl Chloride Repair on SS	.020	420.5	419.5	¼	Light Abrasion (Not Through)
Control		.009	432.0	432.0	¼	
66-221	Polyvinyl Chloride Repair on SS	.020	419.5	418.5	½	Edge Abraded Through 1 in.
Control		.009	409.5	408.0	¼	
67-222	Polyvinyl Chloride	.010	373.0	372.0	¼	Edge Abraded Through 1 in.
Control		.009	437.0	435.5	¼	
65-221	Polyvinyl Chloride	.020	374.0	372.5	¼	Light Abrasion (Not Through)
Control		.009	416.5	415.0	¼	
65-221	Polyvinyl Chloride	.020	372.5	372.0	½	Edge Abraded Through 2 in.
Control		.090	415.0	414.0	½	
149-148	Polysulfide	.012	399.0	397.5	1	Eroded Through
Control		.009	421.5	417.0	1	
162-170	Polyurethane	.020	365.0	363.5	1	Eroded Through
Control		.009	408.5	404.0	1	
143-221	Polyvinyl Chloride over .009 in.SS	.009	454.5	450.5	1	Eroded Through PVC - Not Through SS
Control		.009	421.0	416.0	1	

TABLE 4 (Continued)						
BV No.	Material	Thickness (in.)	Weight (g.)		Test Run (qt.)	Comments
			Before	After		
143-221 Control	Polyvinyl Chloride over .009 in. SS	.020 .009	450.5 432.5	448.5 430.5	½ ½	Eroded Through SS
137-128 Control	Phenolic & Nitrile Adhesive	.027 .009	388.5 425.0	394.5 419.5	1 1	Eroded Through
172-165 Control	Polyurethane	.008 .009	371.0 421.5	370.5 417.0	1 1	Mild Edge Erosion
171-167 Control	Polyurethane	.030 .009	404.0 418.0	403.0 413.0	1 1	Mild Edge Erosion
150-168 Control	Polyurethane	.020 .009	393.0 515.0	393.0 510.5	1 1	Mild Erosion & Edge Damage
161-172 Control	Polyurethane	.020 .009	369.5 427.0	367.5 422.0	1 1	Eroded Through
170-164 Control	Polyurethane	.021 .009	388.5 429.0	388.0 424.0	1 1	Mild Erosion & Edge Damage
160-173 Control	Polyurethane	.020 .009	364.0 421.5	363.0 417.0	1 1	Eroded Through

* Number preceding dash refers to whirling-arm specimen; number following dash refers to materials coded in Tables 1 and 2.

**All controls were full hard 301 stainless steel.

TABLE 5

WHIRLING-ARM RAIN EROSION TEST RESULTS

BV No.		Thickness (in.)	Test Time (min.)	Results
306-222*	Polyvinyl Chloride Pressure Sensitive Tape	.010	15	Top Side Tape Removed
309-222	Polyvinyl Chloride Pressure Sensitive Tape (2 ply)	.020	15	Eroded Through at L.E. 2nd Layer Intact
307-221	Polyvinyl Chloride Pressure Sensitive Tape	.020	15	Small Pits Through Tape
312-221	Polyvinyl Chloride Pressure Sensitive Tape	.020	15	Small Pits Through Tape
194-123	Polyurethane Film	.031	60	No Signs of Erosion
213-124	Polyurethane Film	.031	65	Scattered Pits Not Through
215-204	Liquid Neoprene	.015	65	Light Pitting Not Through
206-2	301 FH Stainless Steel	.009	60	No Signs of Erosion
316-110	Rubber & Phenolic (Asbestos Filler)	.250	37	Erosion Across Face

* Number preceding dash refers to whirling-arm specimen; number following dash refers to materials coded in Tables 1 and 2.

TABLE 6

CORRELATION OF TEST RESULTS AND SERVICE EXPERIENCE

MATERIALS (Listed in descending order of sand erosion resistance)	BV No.[1]	Flat Panel Sand Impingement[2]	Whirling-Arm Sand Erosion[3]	Whirling-Arm Rain Erosion[4]	Sahara Desert Sand Erosion[5]	New York City[6]	Remarks
Polyurethane Film	123	Excellent	Excellent	Excellent	-	-	No service experience
Polyurethane Film	124	Excellent	Excellent	Good	-	-	No service experience
Liquid Neoprene	197	Very Good	Very Good	-	-	-	No service experience
Liquid Neoprene	204	Very Good	Very Good	Good	Good	Fair to Good	Mixed results probably due to application difficulties
Nickel - Electroformed	43	Good	Good	-	-	-	No sand erosion service experience - excellent in rain
Molybdenum - Sheet	27	Good	Good	-	-	-	No service experience
Stainless Steel - Sheet	2	Good	Fair	Excellent	Good	Excellent	Wide usage as rotor blade material
Polyvinyl Chloride - Pressure Sensitive Tape	221	Good	Fair	Poor	-	-	No service experience
Polyvinyl Chloride - Pressure Sensitive Tape	222	Good	Poor	Poor	Good	-	Good for sand erosion field fix - poor in rain
Chrome Plate	35	Fair	Poor	-	Fair	-	Poor for sand
Zinc Plate	33	Poor	-	-	-	Fair	Poor for sand

1 - Refers to materials coded in Tables 1 and 2
2 - Tables 1 and 2
3 - Tables 3 and 4
4 - Table 5
5 - Reference 11, Page 52 (French Military H-21)
6 - References 12 and 14, Page 52. (New York Airways Commercial V-44)

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APPENDIX I

WHIRLING-ARM SAND EROSION TEST SPECIMENS*

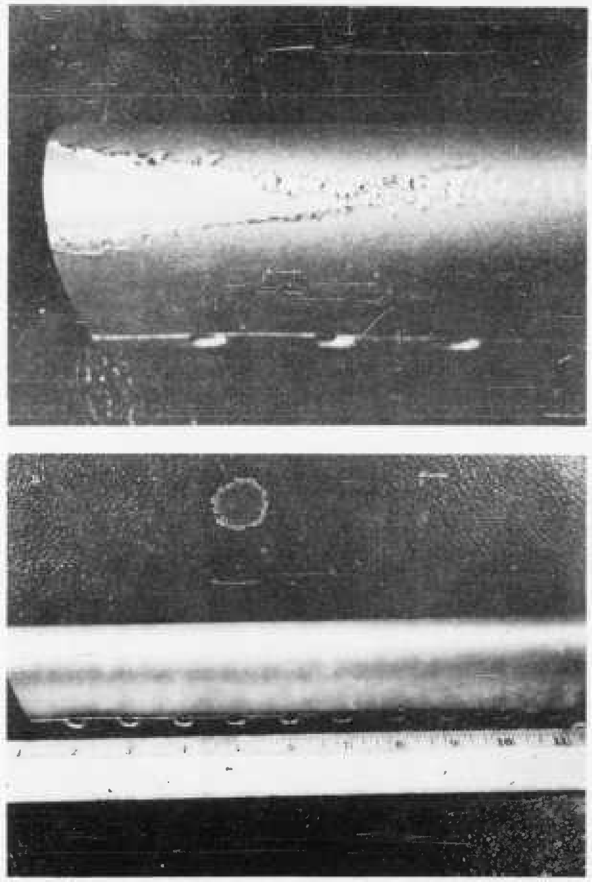


Figure 36. **BV 26-2.**
Full Hard 301SS.
Duration of 1 Run.
Thickness, .009 In.

*See Tables 3 and 4

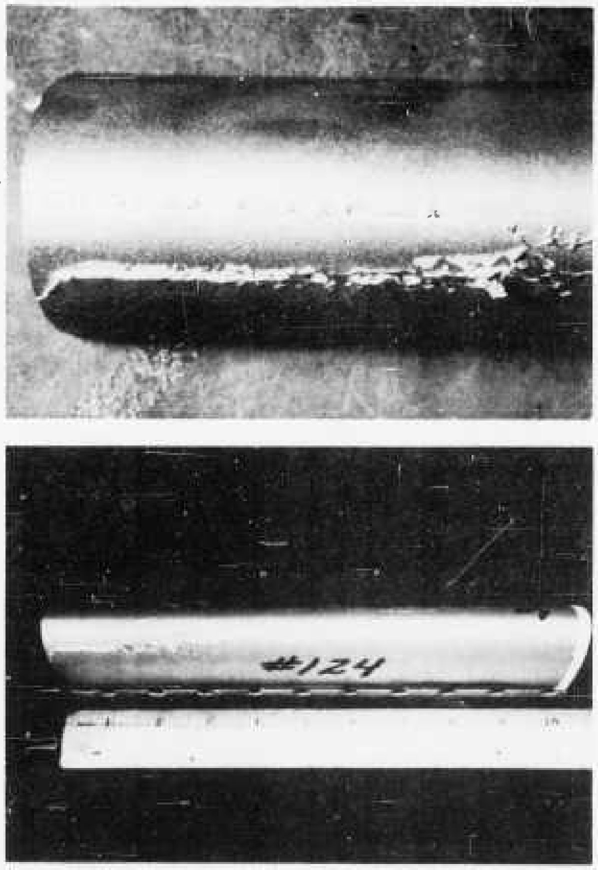


Figure 37. BV 124.
Electroformed Nickel.
Thickness, .009 In.
Duration of 1 Run.

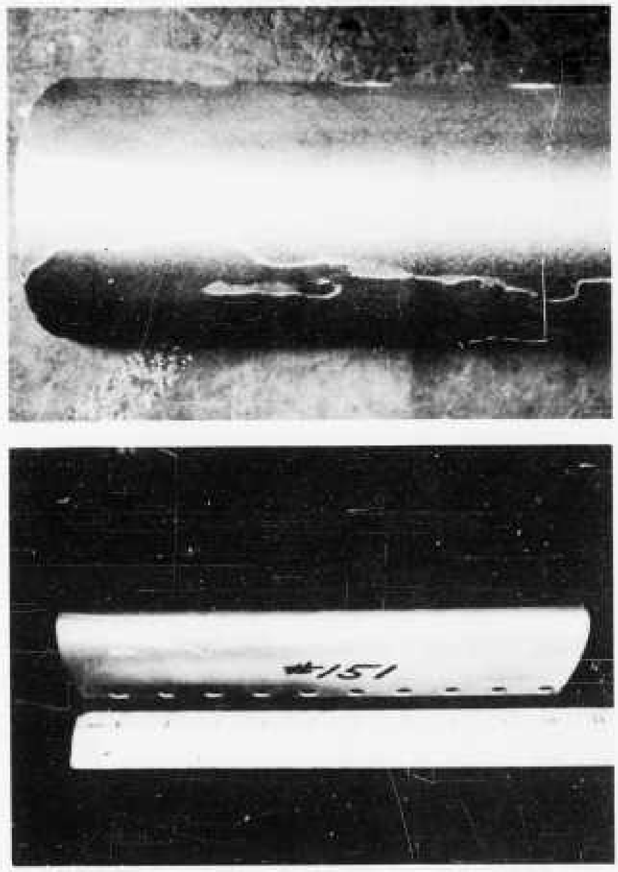


Figure 38. BV 151.
Chrome Plate on Copper.
Thickness, .009 In.
Duration of 1 Run.

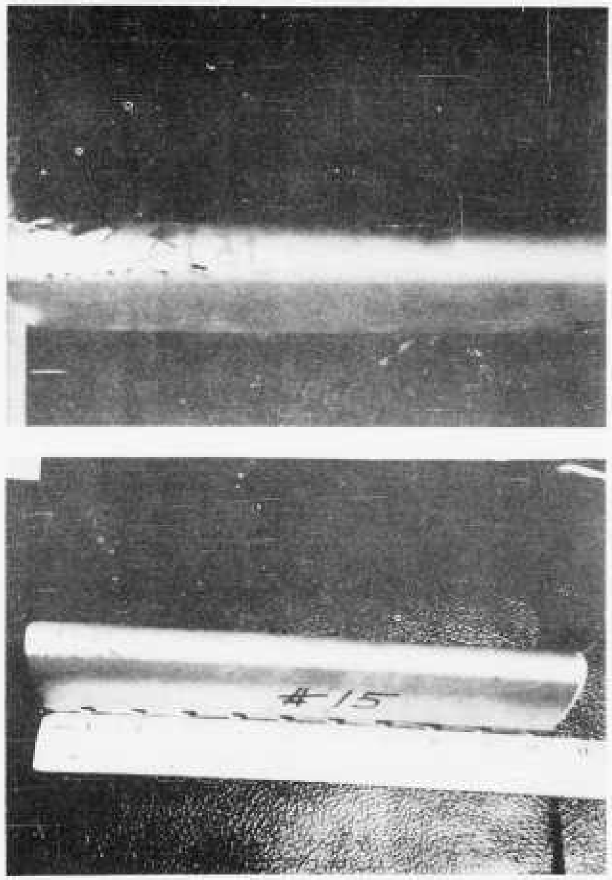


Figure 39. BV 15-10.
13V11Cr3Al Titanium.
Thickness, .012 In.
Duration of 1 Run.

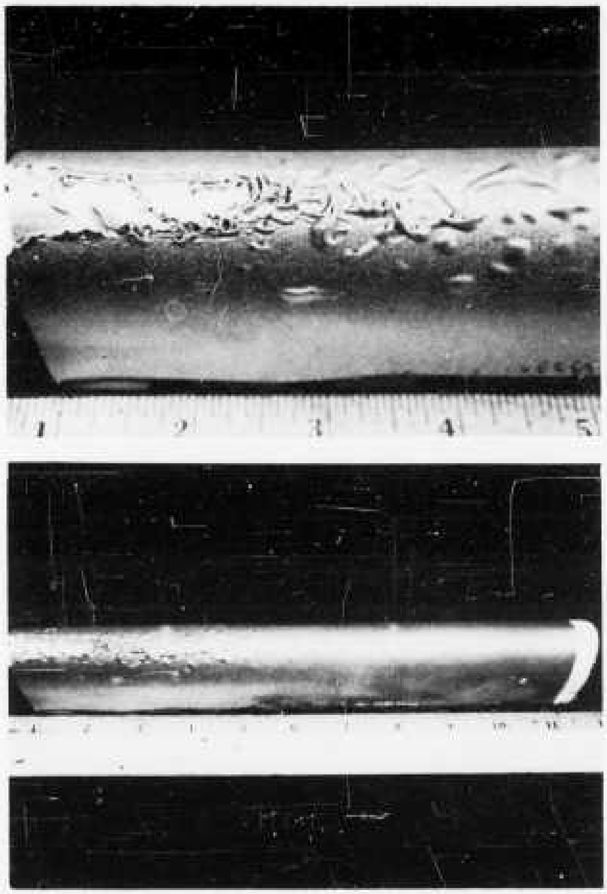


Figure 40. BV 21-18.
Annealed Beryllium Nickel.
Duration of 1 Run.
Thickness, .010 In.

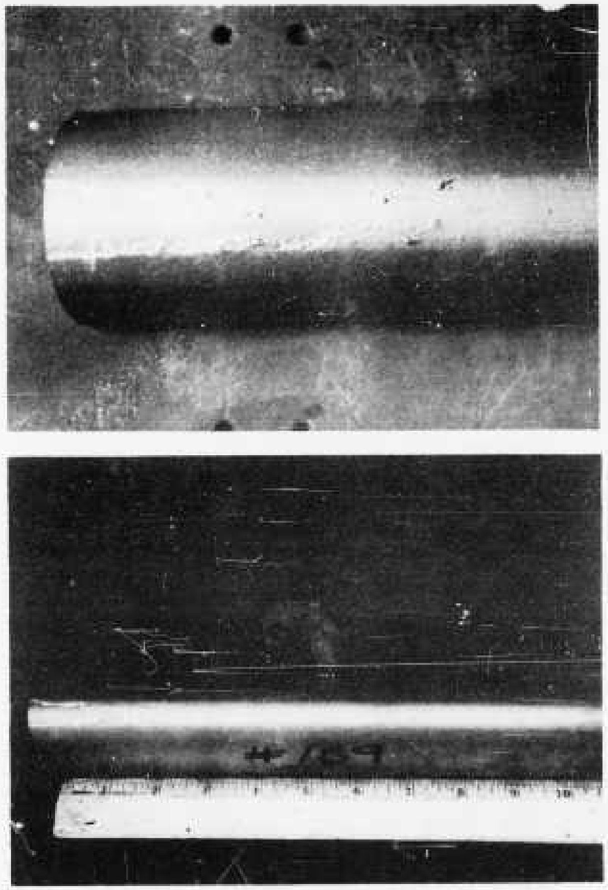


Figure 41. BV 189-26.
Molybdenum.
Thickness, .009 In.
Duration of 1 Run.

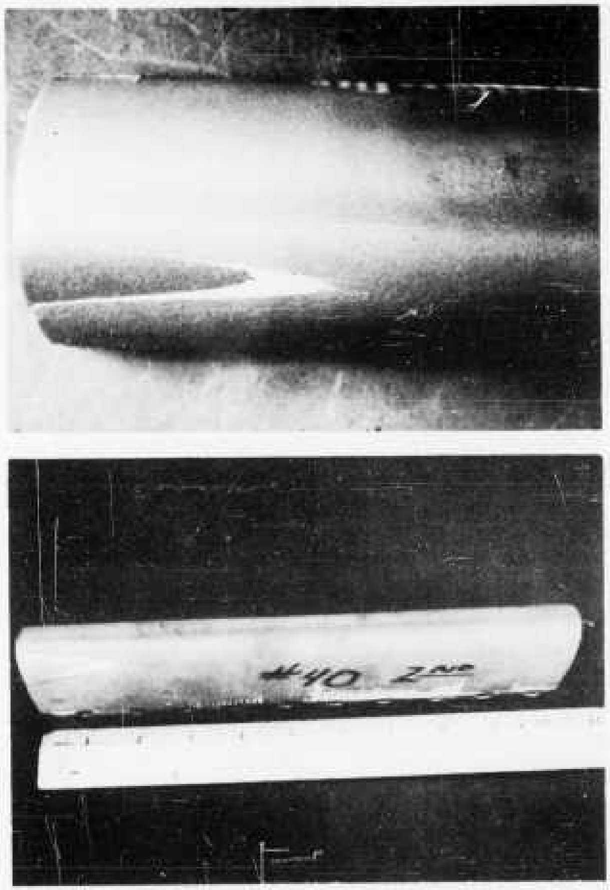


Figure 42. BV 40-126.
Nitrile-Phenolic.
Thickness, .045 In.
Duration of 2 Runs.

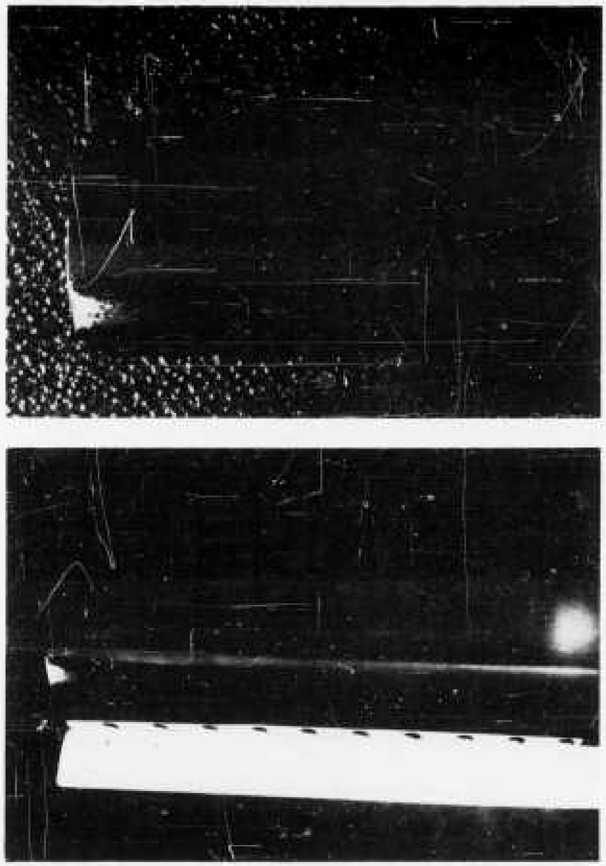


Figure 43. BV 67-222.
Polyvinyl Chloride Pressure Sensitive Tape.
Thickness, .010 In.
Duration of 1/4 Run.

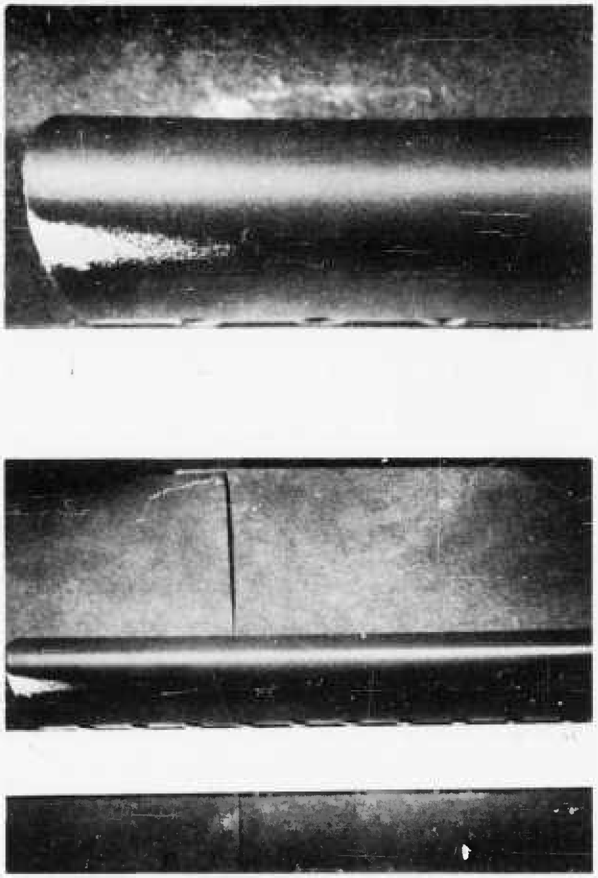


Figure 44. BV 65-221.
Polyvinyl Chloride Pressure Sensitive Tape.
Thickness, .020 In.
Duration of 1/2 Run.

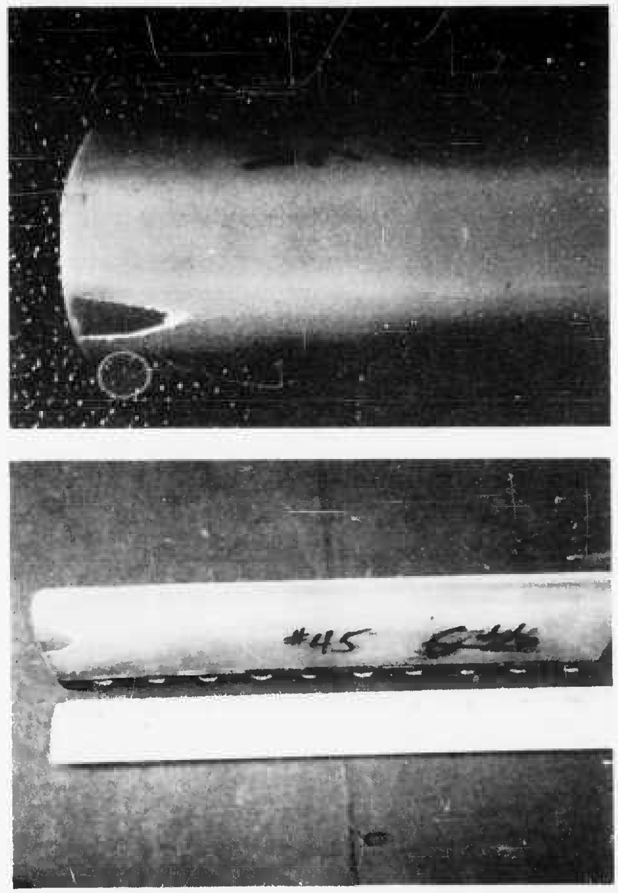


Figure 45. BV 45-124.
Polyurethane.
Thickness, .031 In.
Duration of 6 Runs.

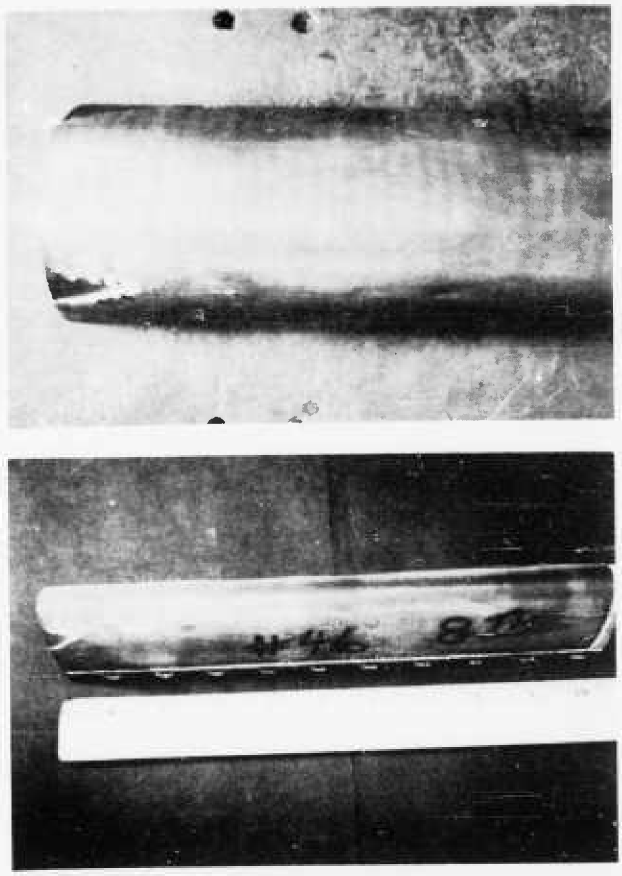


Figure 46. BV 46-123
Polyurethane.
Thickness, .031 In.
Duration of 8 Runs.

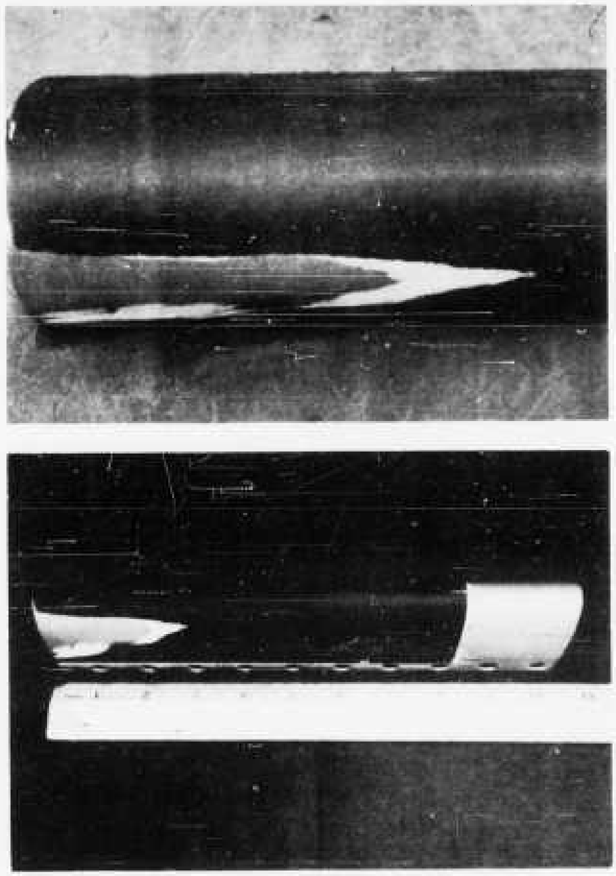


Figure 47. BV 43-109.
Neoprene.
Thickness, .031 In.
Duration of 2 Runs.

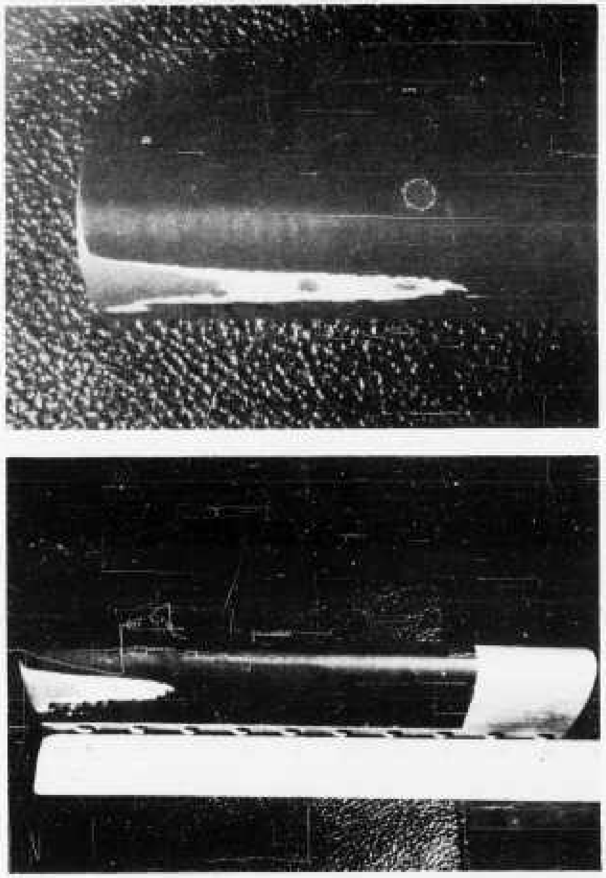


Figure 48. BV 42-108.
Neoprene.
Thickness, .054 In.
Duration of 2 Runs.

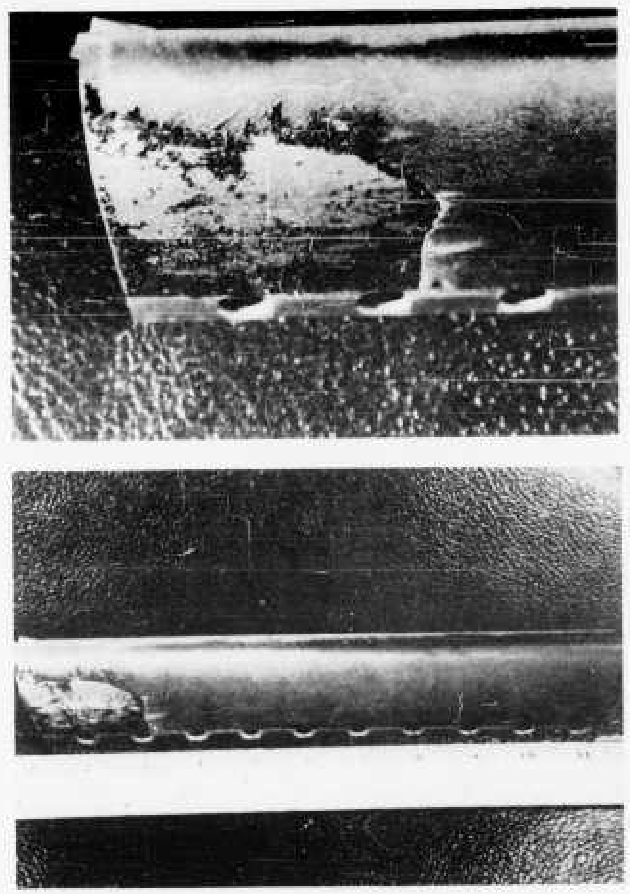


Figure 49. BV 51-114.
Polyvinyl Chloride.
Thickness, .015 In.
Duration of 1 Run.

APPENDIX I

WHIRLING-ARM SAND EROSION TEST SPECIMENS

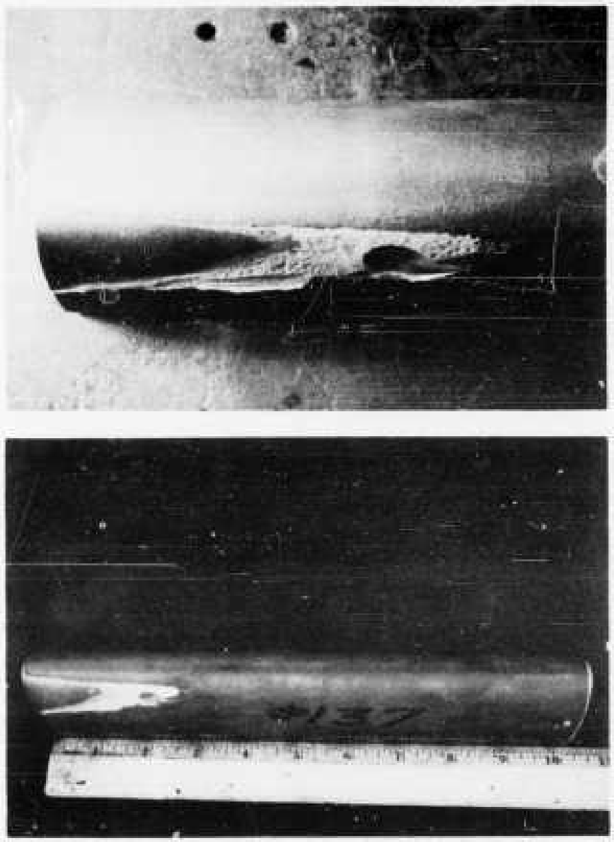


Figure 50. BV 137-128.
Nitrile-Phenolic.
Thickness, .027 In.
Duration of 1 Run.

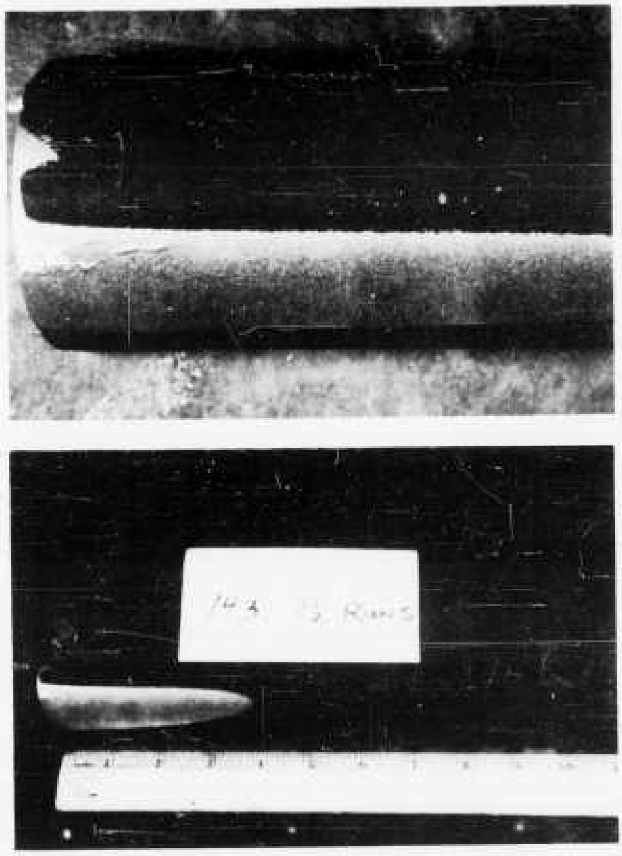


Figure 51. BV 143-221-2.
Polyvinyl Chloride Over Full Hard 301SS.
Thickness, .020 + .009 In.
Duration of 1-1/2 Runs.

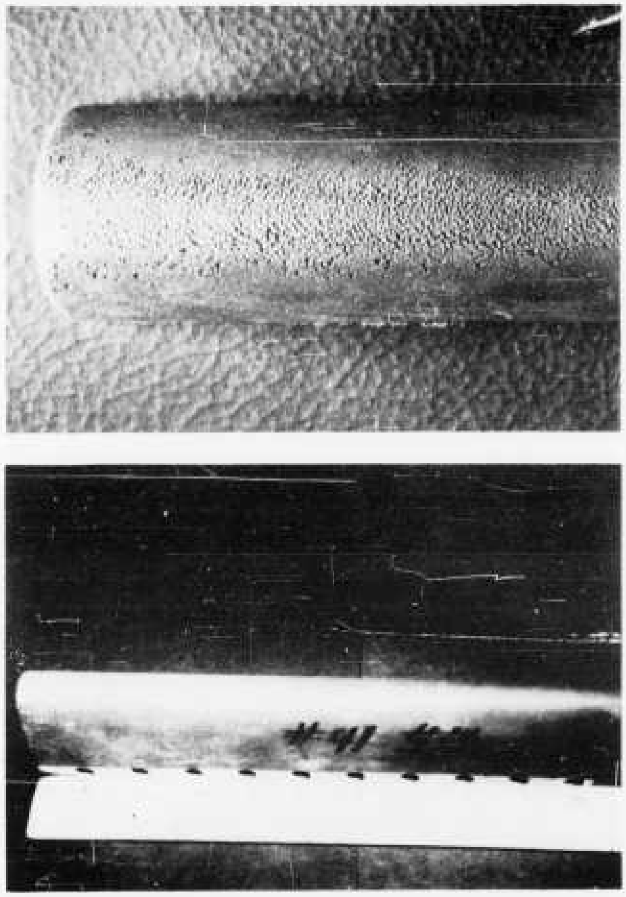


Figure 52. BV 41-204.
Neoprene.
Thickness, .015 In.
Duration of 4 Runs.

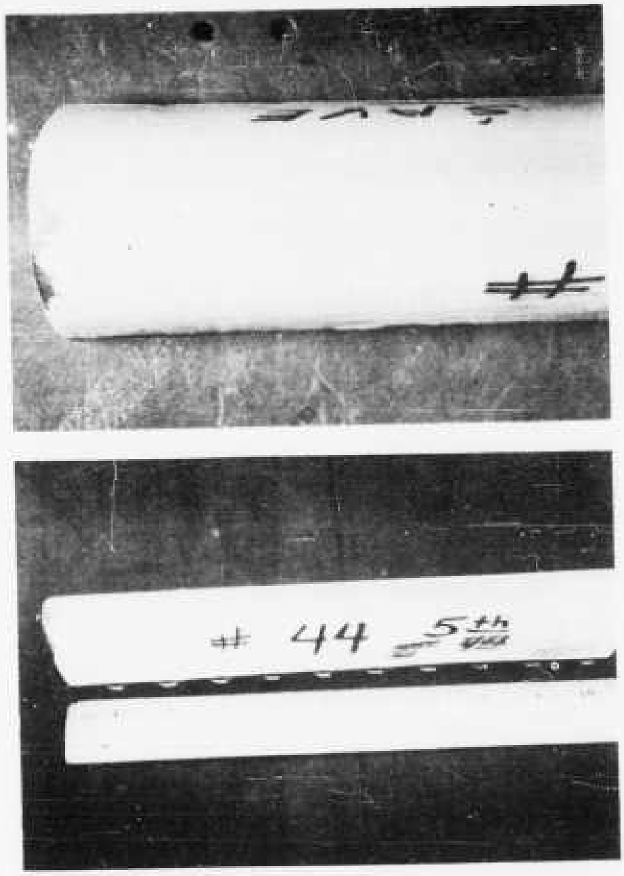


Figure 53. BV 44-197.
White Neoprene.
Thickness, .021 In.
Duration of 5 Runs.

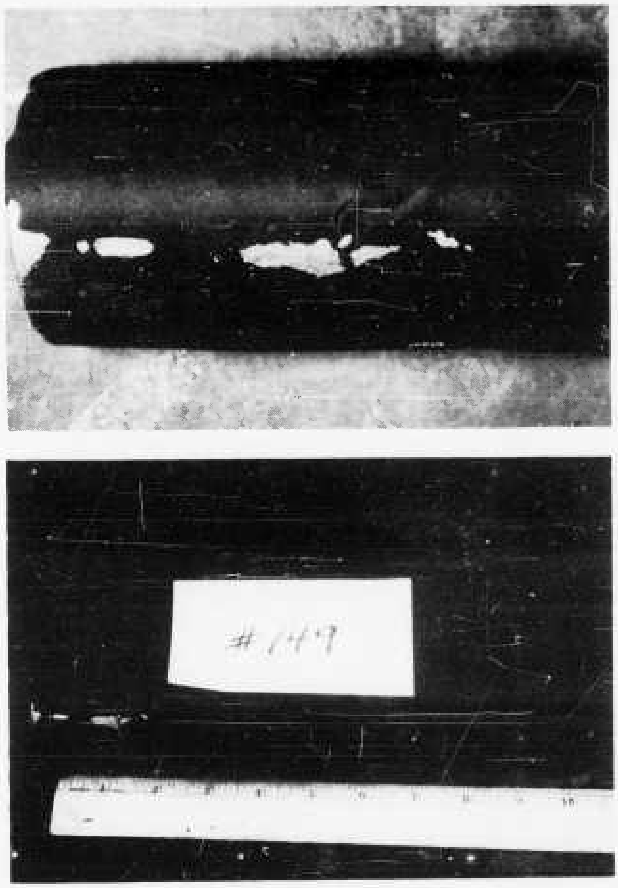


Figure 54. BV 149-148.
Polysulfide.
Thickness, .012 In.
Duration of 1 Run.

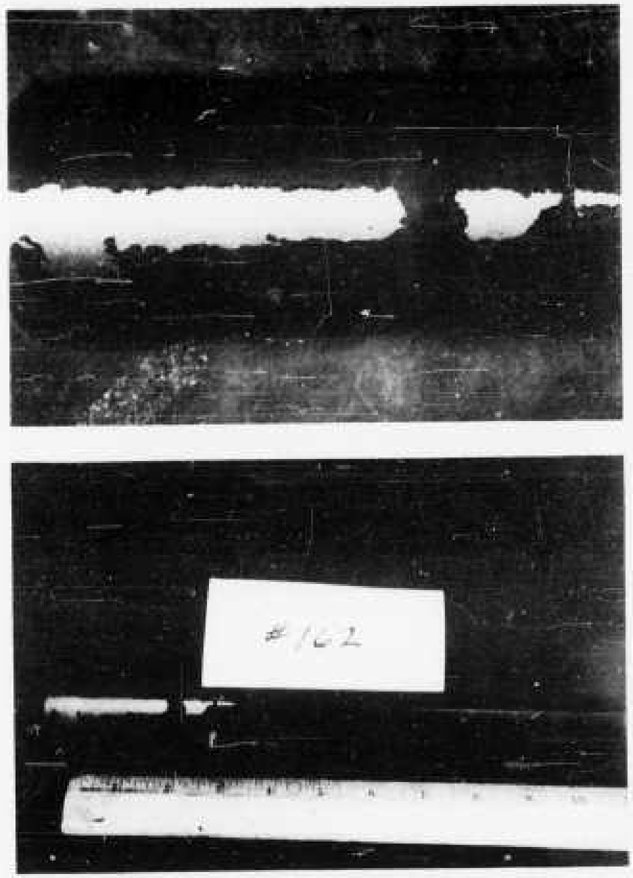


Figure 55. BV 162-170.
Polyurethane.
Thickness, .020 In.
Duration of 1 Run.

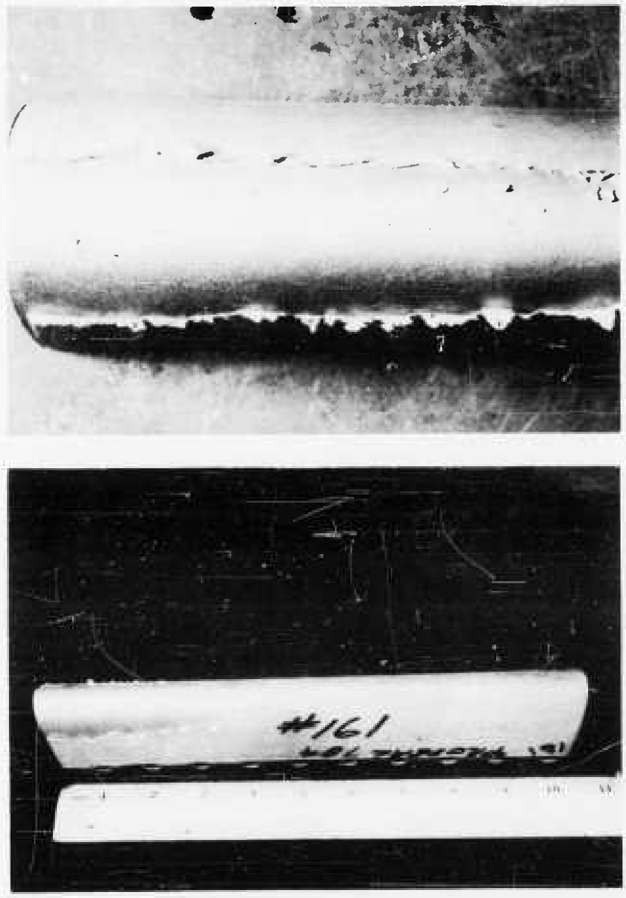


Figure 56. BV 161-172.
Polyurethane.
Thickness, .020 In.
Duration of 1 Run.

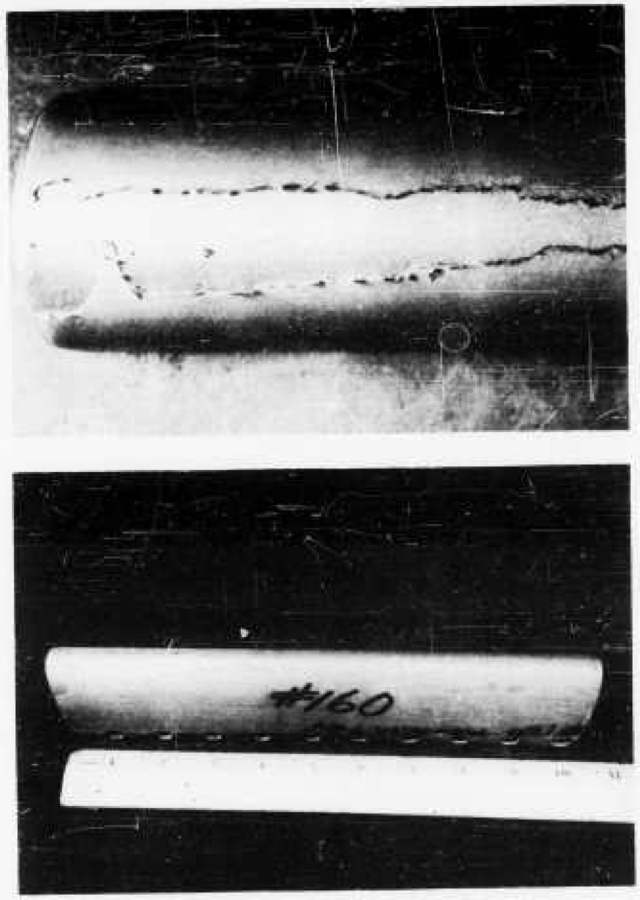


Figure 57. BV 160-173.
Polyurethane.
Thickness, .020 In.
Duration of 1 Run.

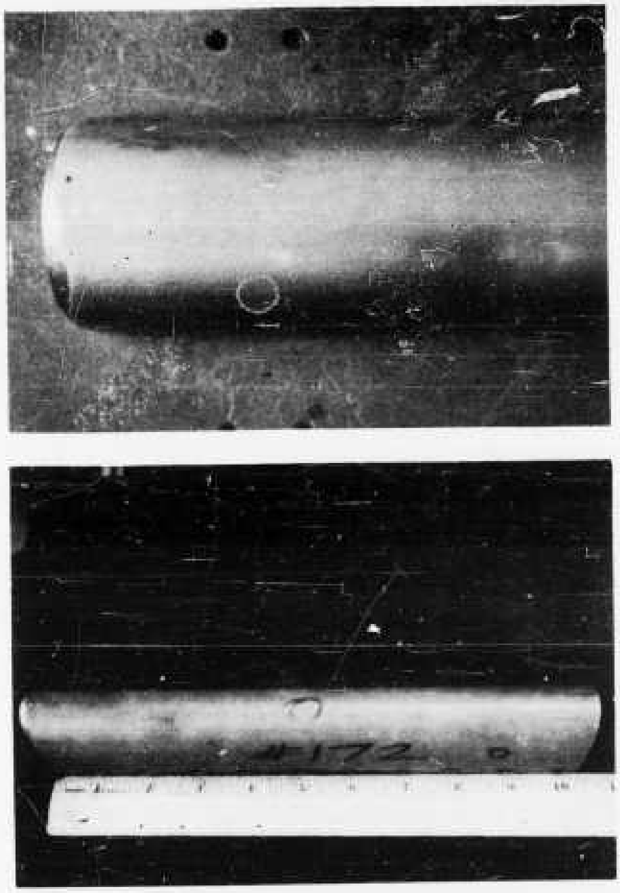
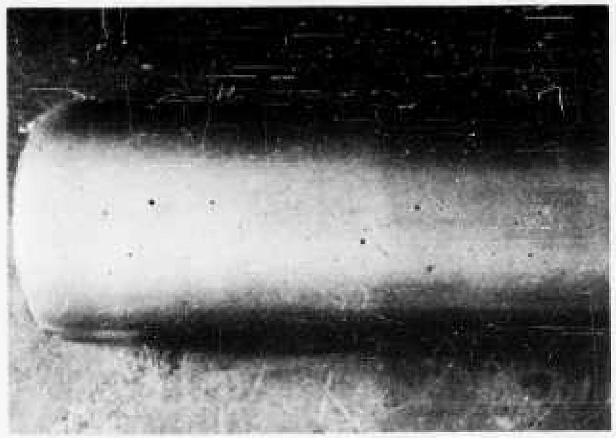


Figure 58. BV 172-165.
Polyurethane.
Thickness, .008 In.
Duration of 1 Run.



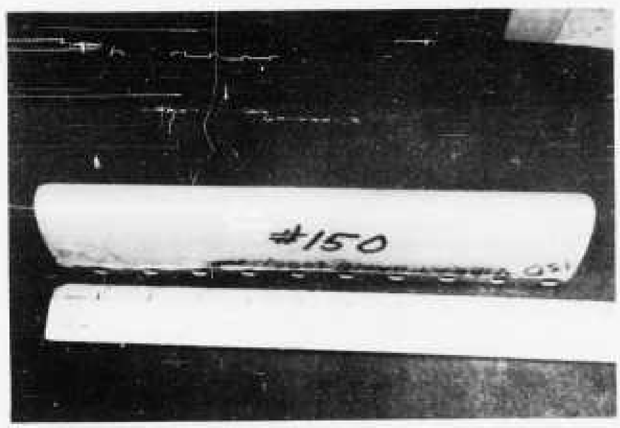


Figure 59. BV 140-168.
Polyurethane.
Thickness, .020 In.
Duration of 1 Run.

APPENDIX II

WHIRLING-ARM RAIN EROSION TEST SPECIMENS*

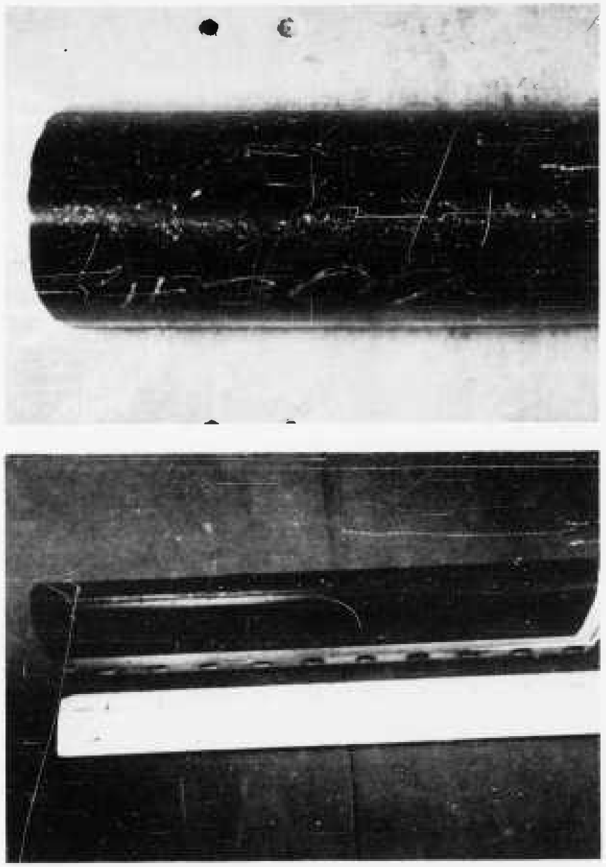


Figure 60. BV 309-222.
Polyvinyl Chloride Pressure Sensitive Tape.
Thickness, .020 In.
Duration of Run, 15 Min.

*See Table 5

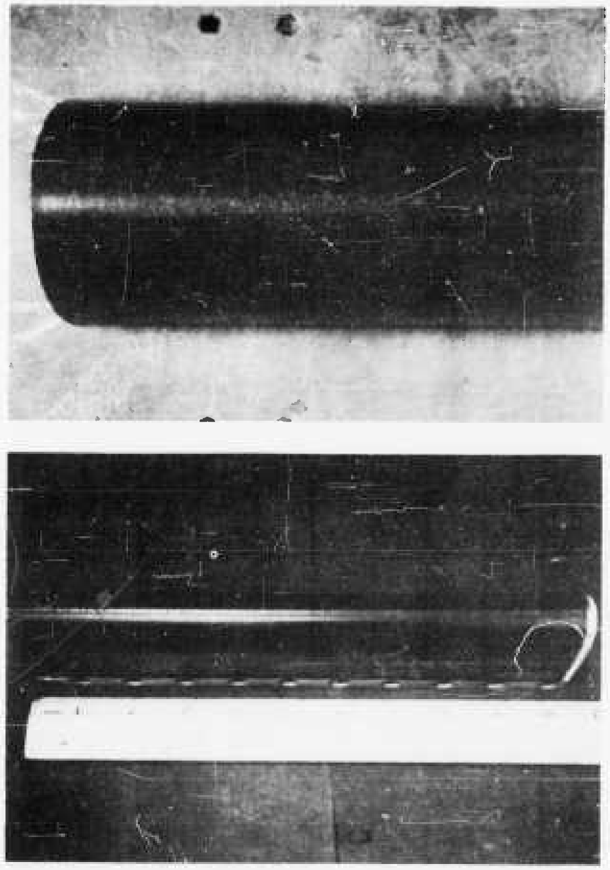


Figure 61. BV 312-221.
Polyvinyl Chloride Pressure Sensitive Tape.
Thickness, .020 In.
Duration of Run, 15 Min.

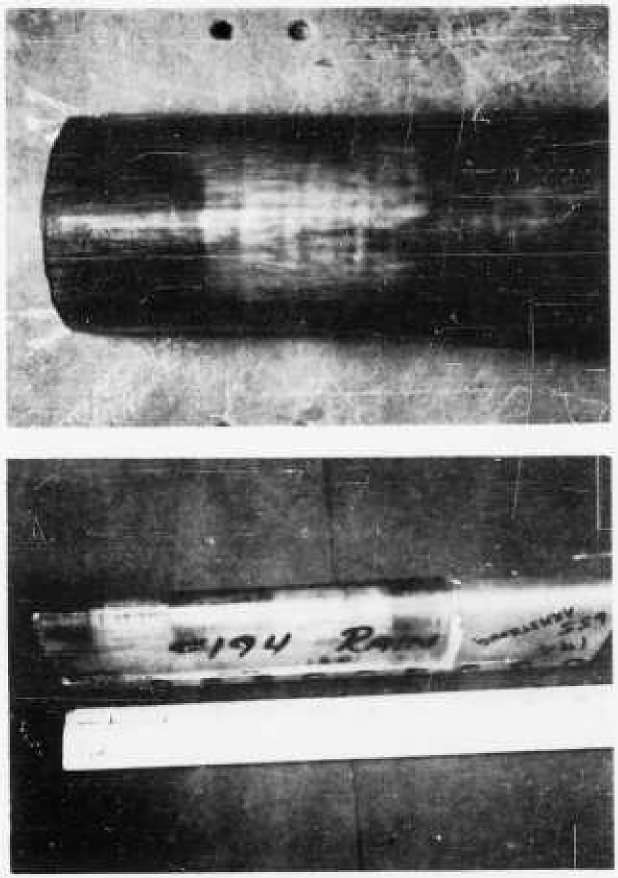


Figure 62. BV 194-123.
Polyurethane Film.
Thickness, .031 In.
Duration of Run, 60 Min.

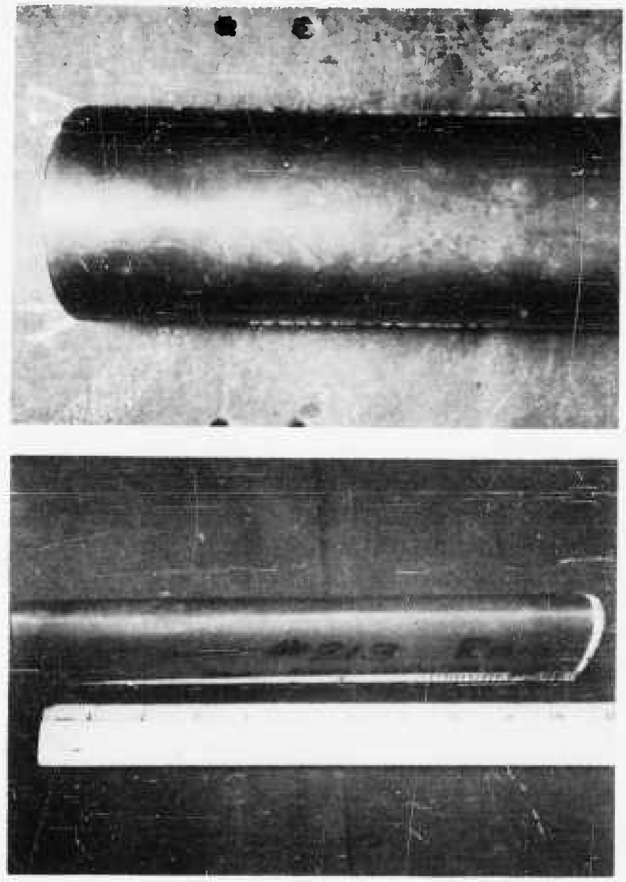


Figure 63. BV 213-124.
Polyurethane Film.
Thickness, .031 In.
Duration of Run, 65 Min.

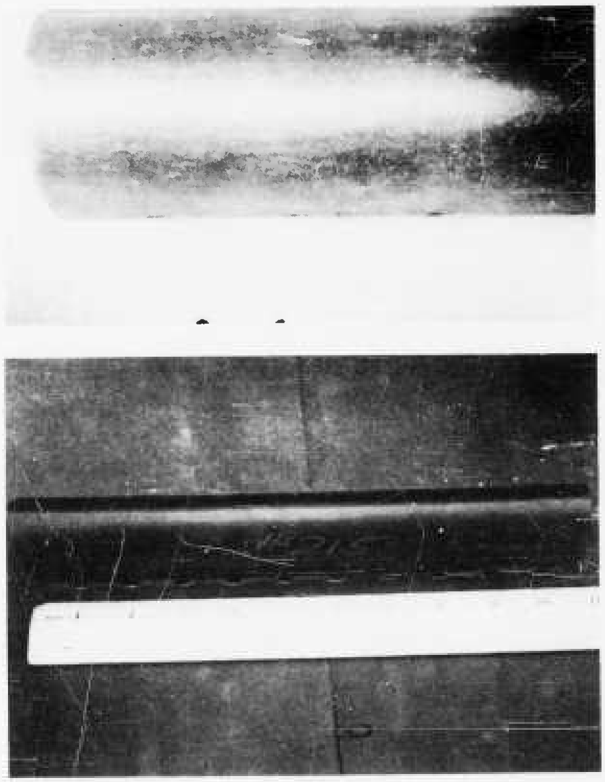


Figure 64. BV 215-204.
Liquid Neoprene.
Thickness, .015 In.
Duration of Run, 65 Min.

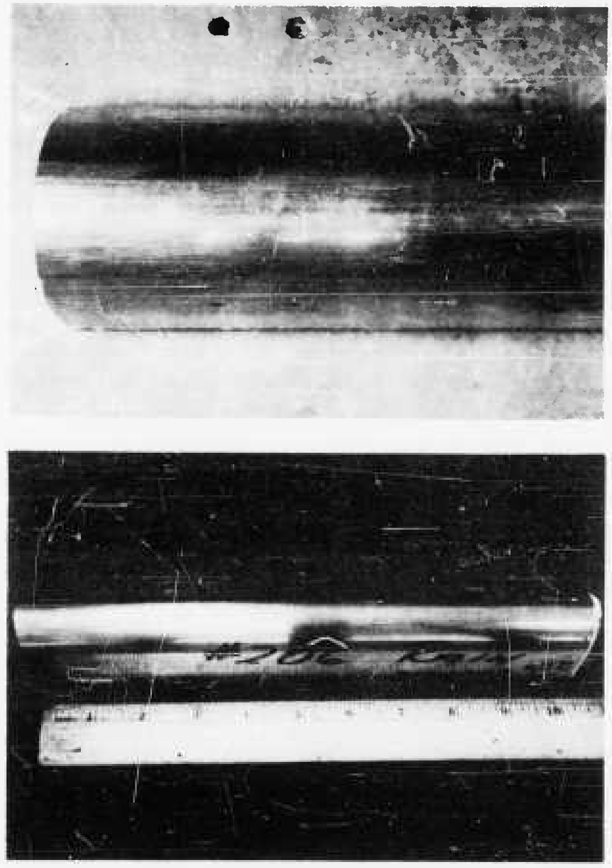


Figure 65. BV 206-2
301 FH Stainless Steel.
Thickness, .009 In.
Duration of Run, 60 Min.

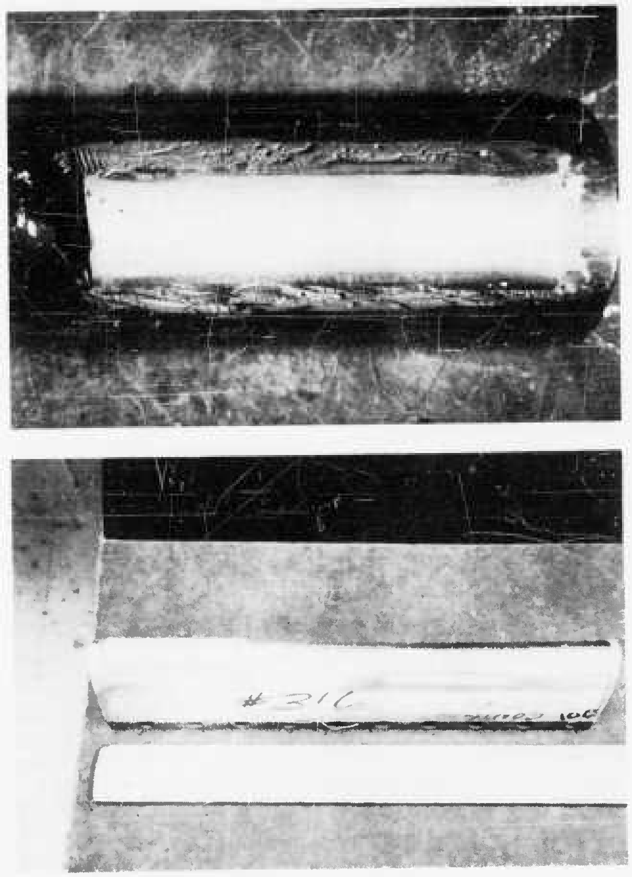


Figure 66. BV 316-110.
E077 Phenolic Rubber and Asbestos
Thickness, .250 In.
Duration of Run, 37 Min.
Convair-TRECOM.

APPENDIX III

SPECIMEN BONDING PROCEDURES

1. Flat Panel Specimens

A. General Cleaning

(1) All backup test panels of 4130 - 9 x 11 x .064 inches were vapor degreased or solvent washed prior to vacuum blasting to remove scale and oxides.

(2) All elastomer film and sheet stock were acetone cleaned and abraded with No. 80 grit emery cloth to remove shiny surfaces, where necessary.

(3) All metal specimens were acetone wiped and soaked 7-15 minutes in a hot solution of alkaline cleaner (160^o-190^o); this procedure was followed by a 3-5 minute rinse in tap water.

B. General Preparations

(1) The materials were weighed to the nearest 0.01 gram.

(2) The mixing and application of material were per the various manufacturers' instructions.

(3) All liquid elastomers were cured at $150^o \pm 5^oF$ for 7 hours to promote a complete cure after 4 to 7 days room temperature aging.

The materials in this test were bonded to satisfy the conditions of sand erosion at room temperature only - no effort or testing was expended to qualify the bonding processes for other conditions or environments.

All metal specimens were bonded with phenolic-nitrile unsupported film adhesive in conjunction with a phenolic primer. The primer was brush applied to both surfaces and allowed one hour air dry before assembly. Cure conditions

were 150-250 psi bondline, $350^{\circ} \pm 5^{\circ}F$ for one hour in a press.

The elastomer film and sheet stock were primed and bonded to the steel backup plate using a neoprene-phenolic primer with one hour air dry before applying an epoxy-amide adhesive and curing at room temperature. One exception was the silicone rubber stock which was bonded with a silicone primer and adhesive.

The liquid elastomers and tapes were applied directly to the vacuum blasted backup plates, except when vendor recommendations required special primer.

2. Whirling-Arm Specimens

The whirling-arm test specimens consisted of a steel leading edge section of a "D" spar with various metals, nonmetals and coatings bonded to this section.

The steel leading edge section was vacuum blasted prior to application of a primer for bonding. An epoxy was used on all metals, and a neoprene-phenolic primer was used for all nonmetal films and sheet stock.

The metal test caps were cleaned by solvent degreasing and by a 7-15 minute soak in a hot solution of alkaline cleaner; this procedure was followed by a cold water rinse. All metal specimens were bonded with an epoxy film adhesive, cured by the vacuum bag process at $350^{\circ}F$ for 45-60 minutes under maximum vacuum.

The nonmetal films were acetone washed, sanded lightly to remove glaze and re-washed with acetone prior to application of a neoprene-phenolic primer. A liquid epoxy adhesive was the bonding agent for the nonmetal films and sheet stock. Pressure was applied by bagging and applying 6 inches of vacuum at room temperature.

An epoxy urethane primer was applied to the vacuum blasted leading edge sections before applying the liquid urethanes which were

cured three days at room temperature and aged at 250^{o}F for three hours.

The liquid thiokols and epoxies were applied to the vacuum blasted leading edge sections, cured three days at room temperature and aged four hours at 150^{o}F to promote a complete cure.

The liquid neoprenes were applied to the primed leading edge sections, cured three days at room temperature and aged three hours at 150^{o}F.

The epoxy film adhesive system resulted in several bondlines having small voids. To test the effects on the erosion characteristics of stainless steel during the whirling arm sand test, specimens were bonded with a liquid epoxy adhesive, which produced a nonporous bondline. No difference in erosion life was noted.

APPENDIX IV

DYNAMIC AND AERODYNAMIC CONSIDERATIONS FOR ROTOR BLADE PROTECTIVE SYSTEMS

Selection of the type and thickness of material for an erosion protective system and the means of application must be carefully adapted to each rotor blade and hub design. Among the factors which must be considered are:

1. Changes in Blade Dynamic Balance - Flying qualities and helicopter vibration level may be affected by the forward shift in the dynamic balance axis. This can occur when weight is added to the leading edge of the blade by application of erosion materials.

2. Changes in Aerodynamic Contour - High speed wind tunnel tests, conducted by Vertol Division, show significant differences in airfoil performance coefficients and in drag divergence Mach number which resulted directly from the method of fairing external leading edge caps and boots into the basic contour. Camber effects can also be introduced if leading edge coverings are not applied with great care.

3. Changes in Blade Section Balance - Addition of material near the nose of the rotor blade moves the section balance forward and changes control system loads. On torsionally flexible blades, this may also have an adverse effect on flying qualities.

4. Changes in Centrifugal Force - Rotor blade retention component strength must be reviewed before adding weight and hence increasing the centrifugal force acting on the rotor system. Roller bearing life varies inversely as the 10/3 power of the load and, therefore, is critically affected. On fully articulated blades, the lag angle will change with the centrifugal force which changes distribution of loading between horizontal pin bearings.

5. Nonuniformity of Application - Differences in weight, weight distribution and contours from blade to blade can produce performance variations and unbalance in the rotor plane which will result in vibration problems. Application tolerances therefore, must be critically evaluated for each blade design.

All of the above factors emphasize the importance of caution and advise against indiscriminate application of protective systems to rotor blades in the field.

APPENDIX V

MASTER CODE LIST FOR ALL METALS AND NONMETALS SUBJECTED TO FLAT PANEL SAND IMPINGEMENT TESTS

APPENDIX V

IS

BOUND

SEPARATELY

DISTRIBUTION

United States Continental Army Command	3
First U. S. Army	3
Second U. S. Army	2
Third U. S. Army	2
Fourth U. S. Army	1
Sixth U. S. Army	1
United States Army Infantry Center	2
USA Command & General Staff College	1
Army War College	1
U. S. Army Arctic Test Board	1
United States Army Armor Board	1
U. S. Army Aviation Test Board	1
Aviation Test Office, Edwards AFB, Calif.	1
U. S. Army Polar Research and Development Center	1
Deputy Chief of Staff for Logistics, DA	2
The Research Analysis Corporation	1
Army Research Office, Durham, N. C.	2
Office of Chief of R&D, DA	1
U. S. Army TMC Navy Coordinating Office	1
Naval Air Test Center	2
U. S. Army Aviation School	2
Deputy Chief of Staff for Military Operations, DA	1
U. S. Army Engineer Research and Development Laboratories	1
Plastics Technical Evaluation Center	2
The Ordnance Board	1
U. S. Army Quartermaster Combat Developments Agency	1
QM Field Support Agency, U. S. Army	1
Communications-Electronics Combat Developments Agency	1
US Army Transportation Board	1
U. S. Army Aviation and Surface Materiel Command	20
U. S. Army Transportation Center & Fort Eustis	4
U. S. Army Transportation School	3
U. S. Army Transportation Research Command	86
U. S. Army Tri-Service Project Officer (MCLATS)	1
US Army Airborne, Electronics and Special Warfare Board	1
Office of the US Army Attaché, UK	1
U. S. Army Research & Development Group (EUR)	1
U. S. Army Engineer Waterways Experiment Station	1

USATDS	5
United States Army, Pacific	1
Eighth United States Army	1
U. S. Army, Ryukyu Islands/IX Corps	2
U. S. Army Transportation Agency, Japan	6
U. S. Army, Hawaii	3
Allied Land Forces Southeastern Europe	2
U. S. Army, Communication Zone Europe	3
U. S. Army, Caribbean	4
Air Force Systems Command (SCS-3)	1
Army Planning Group (PGAPI), Eglin AFB, Fla.	1
Air University Library	1
Aeronautical Systems Division, Wright-Patterson AFB	3
Chief of Naval Operations	1
Office of Naval Research	3
Bureau of Naval Weapons, DN	5
Bureau of Supplies and Accounts, DN	1
Bureau of Yards & Docks, DN	1
U. S. Naval Postgraduate School	1
Hq, U. S. Marine Corps	1
Marine Corps Landing Force Development Center	1
Marine Corps Liaison Officer, USATSCH	1
U. S. Coast Guard	1
U. S. Army Standardization Group, Canada	1
Canadian Army Liaison Officer, USATSCH	3
British Army Staff, DAQMG (Mov & Tn)	4
U. S. Army Standardization Group, U. K.	1
National Aviation Facilities Experimental Center	3
Langley Research Center, NASA	2
George C. Marshall Space Flight Center, NASA	1
Manned Spacecraft Center, NASA	1
Ames Research Center, NASA	2
Lewis Research Center, NASA	1
Scientific and Technical Information Facility	1
Armed Services Technical Information Agency	10
George Washington University Human Resources Research Office	2
U. S. Patent Office	1
Flight Control Laboratory, Wright-Patterson AFB	1
U. S. Army Materials Research Agency	1
Materials Advisory Board, Nat Academy of Sciences	2
U. S. Strike Command	1
U. S. Army Mobility Command	1

U. S. Army Materiel Command	5
Limited Warfare Laboratoy, APG	1
U. S. Army Aviation Maintenance Center	1
U. S. Army Transportation Combat Developments Agency	1

2524-63

Vertol Division, The Boeing Co., Morton, Pa., HELICOPTER ROTOR BLADE EROSION PROTECTIVE MATERIALS - Robert Gilbert, Bruce Zelus, Victor Hribar, and Donald West, TCREC Technical Rept. 62-111, October 1962, 102 pp. (Contract DA 44-177-TC-836) USATRECOM Task 9R38-01-017-69.

Unclassified Report

Development of a system capable of protecting helicopter rotor blades for desert operations is presented. 184 systems were laboratory tested (over)

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2. Contract DA-44-177-TC-836

Vertol Division, The Boeing Co., Morton, Pa., HELICOPTER ROTOR BLADE EROSION PROTECTIVE MATERIALS - Robert Gilbert, Bruce Zelus, Victor Hribar, and Donald West, TCREC Technical Rept. 62-111, October 1962, 102 pp. (Contract DA 44-177-TC-836) USATRECOM Task 9R38-01-017-69.

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